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The Potential for the Culture of Fresh Water Fish in the United
Kingdom Based on Principles of Organic Recycling and Integration
with other Agricultural Systems.

A thesis submitted towards the degree of Master of Philosophy as a
result of work carried out in the Systems Group of the Open
University Faculty of Technology.

Simon Lawson B.Sc. November 1982.

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Abstract.

Fish culture in ponds has been practised in many countries for hundreds of years. It can be a means of producing a high quality protein food from organic wastes and from land that is unsuitable for other agricultural uses. Fish production systems are comparable to other systems of animal production for food and are subject to similar variations in intensity.

In this thesis a general description of systems of fish culture is given and the relevant criteria for comparison with other animal production systems are discussed.

The biological efficiencies of various systems of fish culture are investigated and compared with those of alternative agricultural systems.

Increases in the efficiencies of protein production from integrating fish with livestock production are calculated.

The current status of fish farming in standing water ponds in the UK is described and the potential productivity of manure fed ponds is calculated.

An experiment to investigate the possibility of recycling canteen food wastes through carp is described in Chapter 5.

Resource requirements, economics and marketing for fish culture in standing water ponds are also discussed.

Note: only common names of cyprinid fish are used in the text, specific latin names are given in Appendix 1.

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The Potential for the Culture of Fresh Water Fish in the UK
Based on Principles of Organic Recycling and Integration with
Other Agricultural Systems.

Chapter 1.

Introduction.

Fresh water fish have been cultured in ponds, as an integral part of various agricultural systems for many centuries. The broad principles of animal husbandry apply to fish rearing as to sheep or cattle rearing. The reproduction of the animals is controlled, the young are nurtured, the carrying capacity of the land occupied by the animals is manipulated by the use of supplementary feeds and manures, and care is taken to protect the animals from the ravages of predators and disease.

Today some two thirds of the world's farmed fish are produced in China and elsewhere in the Far East where manures and other agricultural residues are the major feed input, (Wohlfarth and Schroeder, 1979; FAO, 1977; Delmendo, 1980; Pillay, 1976). Similar methods of production are also used to some extent in Israel and Central and Eastern

Europe. However in most of the developed world including the UK, only much more intensive forms of fish culture are practised which involve the feeding of fish with cereal grains or compound feeds which contain a large proportion of animal protein. This type of fish farming has been called "feedlot fish farming".

The development of highly intensive methods of fish farming parallels the intensification of other forms of animal rearing eg the development of "barley beef" and "factory farming" of pigs and poultry. The animals are stocked at high densities in a restricted area, derive practically no nutrition from their natural environment and are thus entirely dependent on feeds supplied by the farmer. The animals raised by such intensive methods, whether trout or chickens, act essentially as converters of feeds from one form to another. Much of the feed converted by intensively reared animals could be used directly as human food if so desired, but it is economically expedient, at present, to convert it to animal products eg meat, fish, eggs and milk. These animal products are all sources of high quality protein for the human diet.

Proteins of animal origin are generally of much higher biological value than proteins of vegetable origin and this provides some nutritional justification for intensive rearing of animals. For example, when pigs are fed a diet of

barley and soya meal, they convert two sources of vegetable protein of low biological value into pigmeat which contains proteins of high biological value. However man has similar dietary requirements to a pig and could if needed satisfy them from soya and barley directly. Indeed sixty-five per cent of man's protein intake is derived from vegetable sources. In Africa and Asia vegetable sources make up about eighty per cent of protein intake, but in Western Europe and North America less than forty-five per cent of the protein intake is from vegetable sources (FAO, 1979). The people in these areas prefer and can afford to consume large amounts of animal produce.

Apart from upgrading the nutritional quality of their feeds animals also convert them into a form that people find more pleasing to eat, and this provides some justification for converting high quality protein feeds such as fish meal and skimmed milk into different animal products. The argument is that these products are not suitable for human consumption largely on aesthetic grounds, and that by feeding them to animals they are converted into aesthetically pleasing foods. However the efficiency with which animals convert their feeds into human food is much less than unity and thus if animals are fed products which could be used directly as human food the total amount of dietary nutrients available for human consumption is reduced. Table 1 shows the efficiency of protein conversion of various animal rearing

Table 1.

The efficiency of protein conversion in breeding populations.
After Holmes (1977)

Product	Edible protein as % of crude protein eaten.
Eggs	22
Broilers	17
Bacon	
12 piglets /yr	14
24 piglets /yr	18
sheep	
1.4 lambs /yr	4.0
2.8 lambs /yr	6.2
suckler beef	
0.9 calves /yr	4.4
1.8 calves /yr	7.4

systems. The efficiency of protein conversion by trout (single animals) intensively reared under UK conditions is similar and may be calculated as follows;

Protein in the diet %	40 - 50	
FCR (dry feed - wet fish)	1 - 1.2/1	(Regier, 1973)
Edible protein as %		
fresh body weight	10	(Edwardson, 1976)
Edible protein as % protein consumed	approx. <u>20%</u>	

It can be argued that in terms of maintaining the food supply of a growing world population that such intensive methods of food production are unjustified because more people could be fed directly from the feeds used to rear animals intensively than can be fed from the animal products so generated. Even considering the short term in a country like Britain, similar arguments can be made, as Holmes (1977) states;

"It can be argued that a reduction in the importation of feeding stuffs, an increase in the degree of self-sufficiency in food and a decline in the contribution of animal foods to the human diet may be necessary even in the short term in Britain if our economic troubles persist, and probably in the long term worldwide as population presses on resources."

He goes on to suggest that;

"Some choice between animals may therefore be necessary so that the best use of resources is achieved individually and

nationally."

Ruminant grazing systems (with the exception of milk production) have protein conversion efficiencies considerably lower than those of intensive pig, poultry and fish production systems, as can be seen from Table 1. However ruminants are able to convert materials which man cannot use directly as food, on biological grounds, eg grass and other cellulosic vegetable matter, into milk and meat which can be used as food. The use of ruminants to collect, and concentrate coarse forages from land that cannot otherwise be cropped (because it is too steep, wet or dry for arable cultivation) results in a net gain of dietary nutrients for man. Similarly feeding ruminants, monogastric animals or fish with feeds that man will not eat because they are unpalatable, such as crop and food processing residues, food wastes, insects, detritus and detritivores, results in their conversion to foods that man will eat and thereby conservation of nutrients that would otherwise be wasted. Traditionally agricultural animals have been used in these ways in most agricultural systems and indeed still are in much of the world today.

It is suggested here that in a situation of current or impending food scarcity that the roles of animals in food production should be as;

(a) converters of resources that are unavailable or

unsuitable for direct human consumption as food.

(b) collectors and concentrators of resources from land that cannot be conveniently cropped by other means.

Furthermore that prominence should be given to systems of animal production that are best suited to meeting these roles in terms of feed conversion efficiencies and productivity per unit area of land.

Where fish are cultured in ponds as an integral part of agricultural systems they often fulfill both roles (a) and (b). A great range of agricultural residues can be converted into fish flesh for human consumption and fish ponds can be constructed on land that is of poor quality for other forms of agricultural production because of its propensity to water logging or flooding. Evidence from other countries suggests that in certain circumstances fish culture in ponds can make more efficient use, in biological terms, of agricultural residues and land resources than other methods of animal production. The hypothesis investigated in this study is that; the introduction of pond fish culture in the UK as an integral part of the UK farming system would result in an increase in the efficiency of utilization of certain classes of agricultural land and other biological resources that are underutilized or wasted at present.

1.1. Fish culture as an integral part of agricultural systems; historical background and current status.

The rearing of fresh water fish for food is an ancient practice in many parts of the world. It is believed that fish (probably tilapia) were cultured in the civilizations of Mesopotamia and Egypt, and there is some evidence of fish rearing from sites around Lake Baikal in Siberia circa 4,000 BC (Kreuzer 1974). The first documentary evidence for controlled breeding of fish and their subsequent rearing comes from China. In about 475 BC Faan Li, a politician and businessman wrote a book entitled "Classic of Fish Culture" in which he describes his method of rearing fish. Hoffmann (1934) quotes a translated passage;

"Construct a pond of six mow and plant many water grasses there. Get twenty female carp three feet long and four males of the same length, and place them quietly in the pond in the second month. In the fourth month put one turtle in the pond, in the sixth month two, and in the eighth month three. Then in the second month of the next year you will get 15,000 one foot carp, 10,000 two foot carp and 45,000 three foot carp, and these can be sold for 1,250.00 cash. In the third year you get 100,000 one foot carp, 50,000 two foot carp, and the rest can be sold for 5,150.00 cash. The carp

will not harm each other and can easily be reared."

Carp have also been reared in Japan for about 1900 years and Suzuki (1976) writes that intensive carp culture has long been practised in Nagano, Gunma and Yamagata prefectures because they are far from the sea and hence have a poor supply of marine fish and once had an abundant supply of silk worm pupae for carp feed. According to Hoffmann (1934) no advances on Fan Li's methods were documented until the Ming Dynasty 1368-1643 AD. In 1639 "A Complete Book of Agriculture" was published, in this and other sources of the period, there is considerable information about the pond fish culture techniques prevalent in China at the time. References are made to the use of specially constructed breeding ponds, fry feeding with egg yolk, wheat bran and powdered beans, the polyculture of chinese carp, the feeding of larger fish with grasses, green vegetables, hemp leaves, weed seeds, sheep excreta (from sheep grazed on the pond banks), night soil, other animal manures and compost. There is also information regarding pond management, different ponds for different size classes of fish, predators, fish diseases and their control.

"Certain Experiments Concerning Fish and Fruite: Practsed by John Taverner and by him published for the benefit of others." was printed in London in 1600. This treatise on the husbandry of fish in England refers to techniques and

practices of fish culture similar to many of those outlined in the Chinese literature of the same period. Taverner makes observations on the breeding of fish, polyculture of carp, roach, tench and bream, feeding of sodden grains and malt to bigger fish, and the value of grazing cattle near ponds. Taverner also suggests rotations in which ponds are left dry every other year and grazed with cattle or cropped with corn. In referring to stocking rates and the related amounts of fish growth and necessary feeding, Taverner makes an analogy with cattle and sheep husbandry.

"It is with fish as it is with other creatures, for like as one acre of ground will hardly feede one oxe throughout the yeare, to keepe him in good plight and fat, yet so much corne of hay you may lay in that, acre, that you may feede ten or twentie oxen. And even so, although one acre of ground overflowed with water, will naturalie and if itselke keepe but 300 or foure hundreth carpes or other fishes: yet so much feeding may you add there unto, that it may keepe three thousand or foure thousand in as good plight as three hundreth or foure hundreth without such feeding."

In 1794 Roger North wrote;

".. when water happens to recieve the wash of the commons where many sheep are fed, the water is enriched by the earth and shall feed many more carps than otherwise it would."

"The dung that falls from cattle is also a very great nourishment of fish."

The examples cited above illustrate that in the past systems of fresh water fish culture were integrated to some extent with other agricultural systems. Direct use was made of outputs from systems of animal or crop production, such as manures, silk worm waste and cereal by-products. This situation continues into the twentieth century.

Hoffmann's study of fish culture in south China which was carried out in the 1920's and published in 1934, gives a good indication of the extent of integration of fish culture and other agricultural systems at that time. Silk production was a major activity in Kwangtung province and there was an intimate relationship between silk production and fish culture. Because the area was low lying and prone to flooding, mulberries could only be grown on banks thrown up above the level of the water table, and the resulting ditches were used for fish culture. By-products of silk production eg silk worm excreta and pupae were used as fish feeds. Fruit trees were also grown on banks and the ditches used as fish ponds, (the author has observed that a similar method of fish and fruit production exists in the low lying plains of Thailand today). Fish were also reared in ponds made from, disused brick pits, and on a seasonal basis in temporary ponds used predominately for storing irrigation water and for bathing water buffalos. Hoffmann states that the production of fish from these temporary ponds was;

"incidental but not inconsequential."

A great variety of agricultural residues and by-products were used as fish feeds as is shown in Table 2 from Hoffmann. The importance of night soil and farm animal excreta in fish production is illustrated by the fact that the rent of village fish ponds was often evaluated by the number of inhabitants of a village and the number of livestock kept. Excreta was often the main or sole source of fish feed in such ponds. However fish culture was not simply a user of the products of other production systems but also contributed to them. The bottom mud that accumulated in fish ponds was periodically excavated and used as fertilizer for arable and horticultural crops. Rotations in the use of fish ponds for fish and vegetable production were practised this served two purposes. Firstly, fertility was maintained because after a fish crop the bottom mud of the pond provided nutrients for the vegetable crop and the decaying remains of the vegetable crop served to enhance production of the subsequent fish crop. Secondly, by devoting half of their land to each activity farmers could spread the risk of crop failure and fluctuations in market prices. Lin (1940) reports similar practices of fish culture in the New Territories of Hong Kong, and writes of the multiple use of ponds for fish, vegetable production and irrigation.

Table 2.

The cost of fish feeds in China. (Hoffmann 1934).

FEEDS	PRICE PER 100 CATTIES	PRICE PER PICUL
grasses		.25
waterweeds		.1-.4
vegetables		cost of labour
silkworm pupae	.15	
peanut cake		7.8
rice bran		4-5
broken rice		2
hog manure		4-5
silkworm waste	.2-.5	
horse manure	.5	
distillers waste	.2	
cow manure	.06-.2	
night soil	.7-1	
bean cake		5

Hickling (1948) in a review of the fish culture practices of the Near and Far East discusses the reclamation of land, in coastal areas of Java, for paddy cultivation. He states that the first stage of reclamation was the construction of fish ponds. After a few years the salinity of these ponds became reduced to the extent that it was possible to grow rice in them. Further fish ponds were then constructed on the coastal side of these new paddies and the reclamation of land continued. The integration of pig and duck raising with fish culture is also mentioned. Fish culture practices in China, Singapore, the Dutch East Indies, Philippines, Hong Kong and Palestine are discussed in the same paper. In all these areas some use was made of animal manures and other agricultural residues as inputs to fish culture.

The integration of fish culture and other agricultural systems was not confined to the East however. Smith and Swingle (1942) report their experiments, on the use of organic fertilizers for fish ponds, in the USA. In this work they used crop processing residues such as soya meal, and animal manures to increase fish pond yields. They also refer to other US work in this field.

In 1954 Mortimer and Hickling published their extensive review of the literature on fertilizing fish ponds. This work includes abstracts of some three hundred and fifty European and other publications on this subject. Wunder

(1949), writing about fish culture in Germany, extols the benefits of long dry fallows for carp ponds and claims that the use of the ponds for meadow or cultivation during the fallow period can double subsequent fish yields. He also refers to the stimulating effect of manures on the growth of natural fish feed in ponds, and the integration of fish culture with geese and duck raising. Other references in Mortimer and Hickling's work refer to the use of organic manures as inputs to fish culture in Palestine, Germany, Malaya, India and elsewhere. De Bont (1948) reports good production rates for tilapia, raised on sweet potato, banana leaves and maize mill sweepings, in the Belgian Congo. Suzuki (1976) states that the growing of carp in rice paddies and their supplementary feeding with silk by-products was commonplace in Japan earlier in this century but that this has largely died out due to the toxic effects of DDT and other pesticides on fish.

The current status of fish culture as an integral part of agricultural systems is not much different from that in the earlier part of this century. Undoubtedly the zenith of integration of fish culture and other agricultural systems is now to be found in China, the extent of this integration is emphasised repeatedly in the FAO publication "Fresh Water Fisheries and Aquaculture in China." (FAO 1977). Edwards (1980) points out that it is only in China that fish farming and animal husbandry seem to be integrated on a large scale.

However there are still examples of truly integrated systems in many other countries. Integrated systems are defined here as being;

"..those that make direct use of an output (by-product) of an agricultural enterprise carried out on the same holding."

Delmendo (1980) cites several examples of systems that qualify as being integrated in these terms, eg livestock cum fish farming systems in Vietnam, Thailand, Malaysia, Indonesia, Hong Kong, Philippines, Central and Eastern Europe, Nepal and India. The livestock most commonly associated with these systems are ducks and pigs, but horses, sheep, cattle and chickens are also mentioned. Delmendo (ibid.) also cites examples of integration of fish and rice production in the Philippines and Indonesia. The author has observed that in Thailand fish are cultured in orchard ditches which are fertilized as a result of run-off of fertilizers applied to the banks on which fruit trees are grown. Muller (1978) describes an "Aquacultural Rotation" practised in Hungary that involves fish, rice, ducks, and forage legumes. Nugent (1978) reports work with both poultry and fish, and pigs and fish, in Central Africa. In Israel the use of both cattle and poultry manures in fish farming is now assuming considerable importance as a major means of fish production (Wohlfarth et al. 1979; Allen and Hepher 1976).

In most of Western Europe, the USA and Japan however

integrated fish farming systems are now of little significance or indeed are non-existent as is the case in the UK at present. In these areas the dominant mode of fish culture is that of "feedlot fish farming". The reasons for the decline of fresh water fish culture in the UK are not clear. Kreuzer (1974) suggests that the Reformation was responsible because of the association between fish culture and the monasteries. However there is evidence that fish culture was still practised to some extent after the Reformation and that fresh water fish were still an important source of food after this period, (Taverner, 1600; Drummond and Wilbraham, 1959). The increased availability of marine fish in inland areas due to improvements in transportation, preservation, and the efficiency of the marine fishing fleet during the nineteenth century led to the final abandonment of fish culture (Reay, 1979). Today the only significant production of fresh water fish in the UK is that of trout by intensive methods. This form of production has only developed in the UK over the last twenty years (Lewis, 1979).

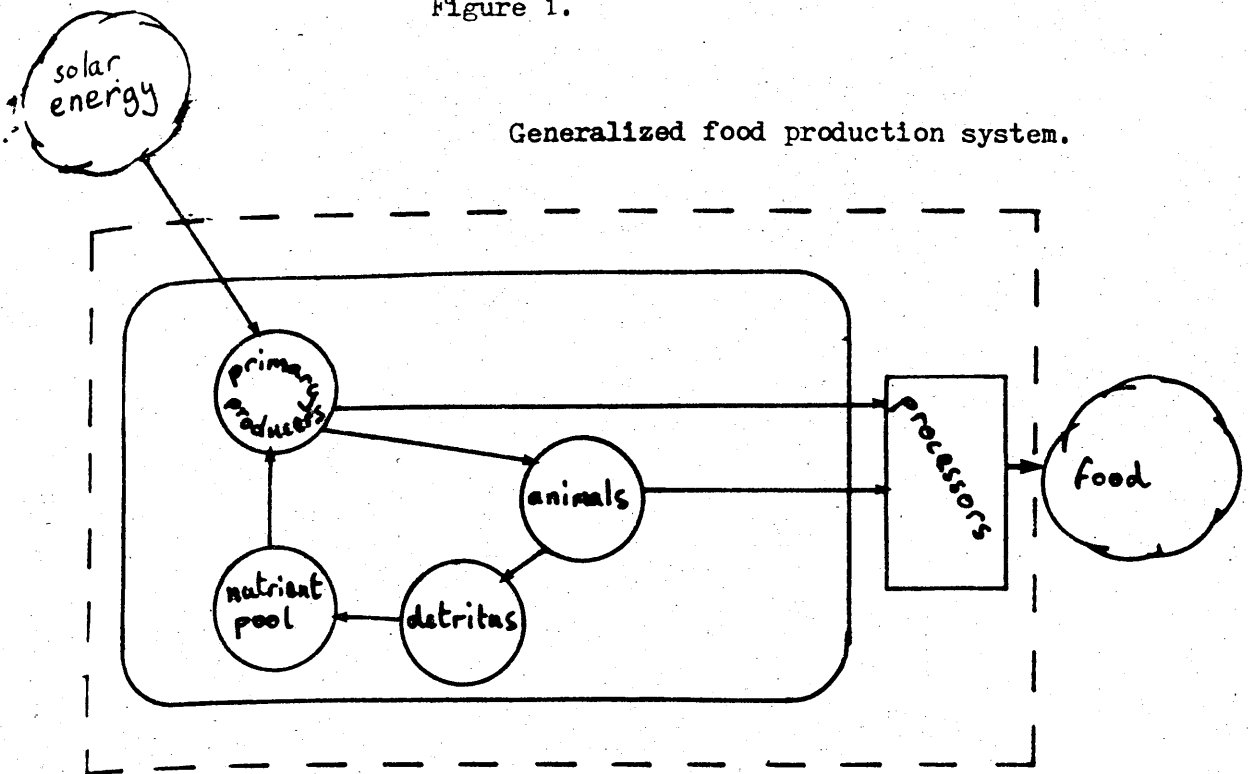
1.2. General description of systems of fish culture in ponds.

In general terms a fish pond may be considered to be a system for converting various materials into fish flesh, the system boundaries being the physical boundaries of the pond itself. Essentially the conversion processes within the system are similar to those within all other systems of food (material) production that involve both primary and secondary producers, it is the nature of the convertors that varies. (Strictly speaking almost all crops and animals must be processed in some way before they are suitable for consumption as human food, in this case processors are considered to be outside the food production systems under consideration). At their most basic level all food production systems convert solar energy into food (human fuel). Figure 1 illustrates a generalised food production system and a fish pond.

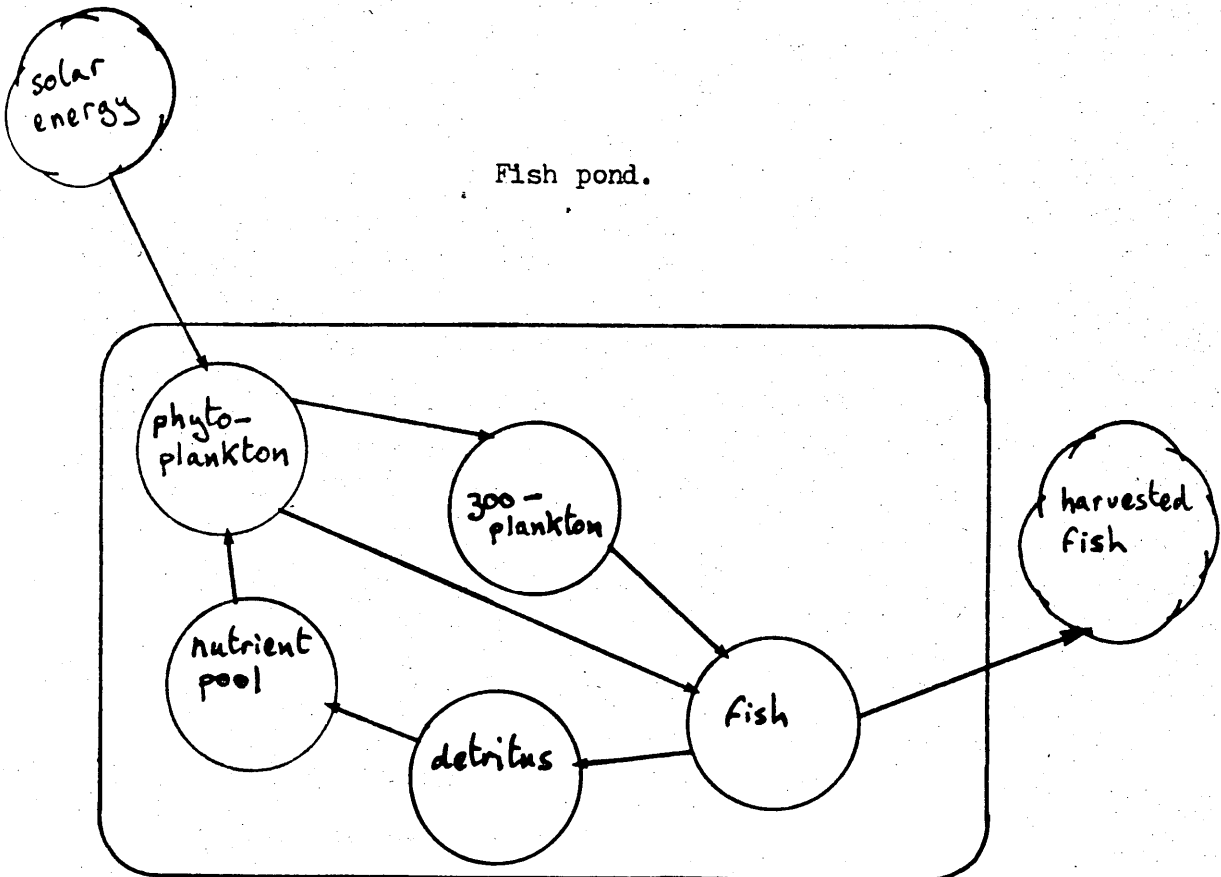
In any food production system solar energy and inorganic nutrients are fixed as plant material by photosynthesis. This plant material may then be processed in some way for use as human food or may first be consumed by animals, which themselves are processed into food.

Figure 1.

Generalized food production system.



Fish pond.



In a fish pond, inorganic nutrients in the pond water are fixed into organic matter by phytoplankton and to a limited extent by macrophytes (primary production). This organic matter is subsequently grazed by zooplankton (secondary production) which form the main food of many fish. There are some species of fish used in fish culture which do feed directly on primary production eg silver carp (on phytoplankton), grass carp (on macrophytes) and some tilapias on both, however fish such as common carp feed mostly on zooplankton and other animalcula.

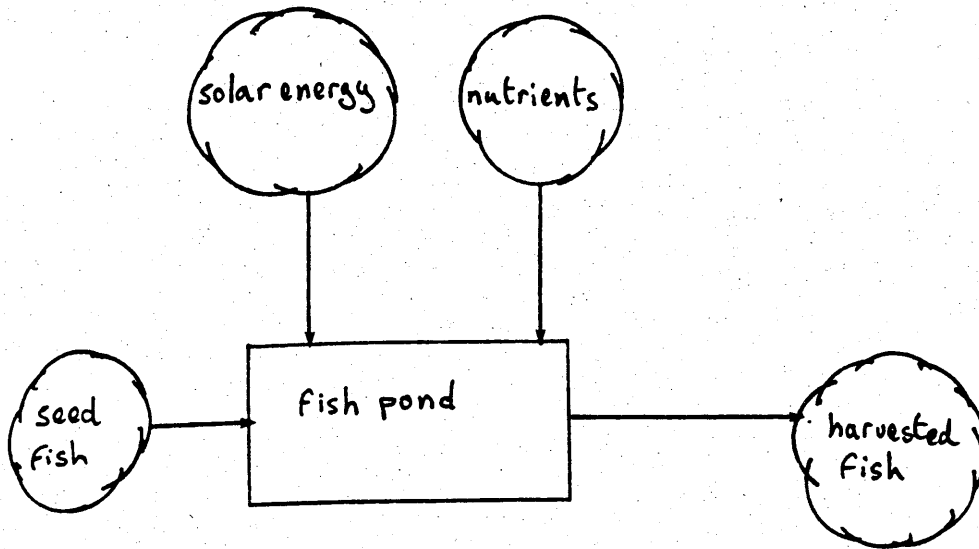
In common with other food production systems the output of a given fish pond system can be manipulated by increasing the number of inputs to the system eg by adding fertilizers or supplementary feeds.

For the purposes of this discussion it is convenient to treat a fish pond as a black box and Figure 2 shows the basic system. Usually if fish are to be extracted from the system as an output then seed fish must be an input to the system, unless reproduction takes place within the pond.

Conceptually the fish production system outlined in Fig.2 is analagous to an extensive ruminant grazing system, in which inorganic nutrients are fixed into plant material and converted into meat. The micro-organisms in the rumen

Figure 2.

Basic fish production system.

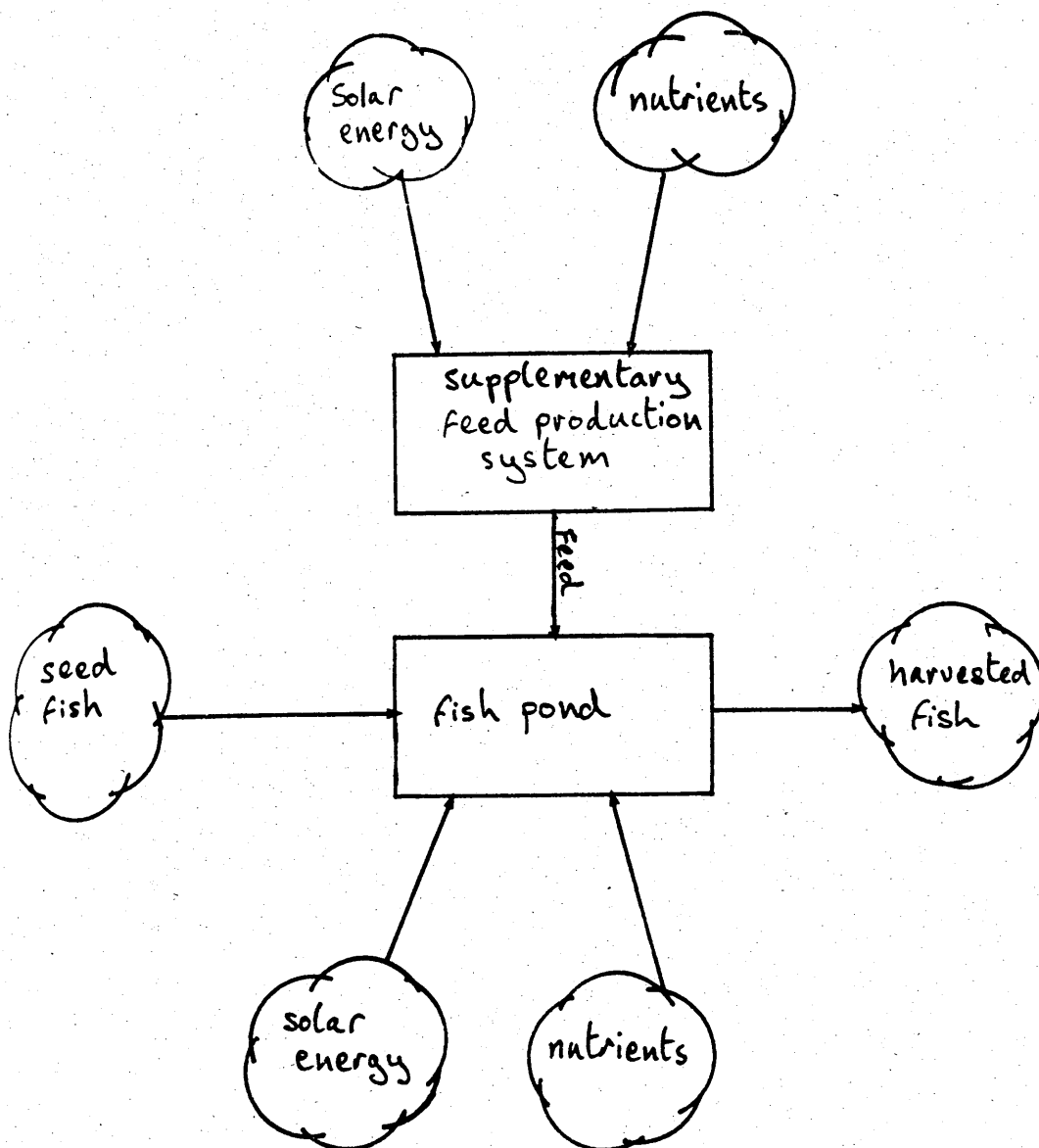


function in a similar fashion to the zooplankton in a pond ie by making cellulosic plant material available for the nutrition of the animals. In both systems inorganic materials for plant growth occur as a result of the natural fertility of the soils on which the pond is constructed or the ruminants are grazed, and the animals within the systems act as collectors and concentrators of materials which are unsuitable as human food and convert them into a form suitable for human consumption. The waste products excreted by the animals are recycled by natural processes within the systems.

The addition of fertilizers (either organic or inorganic) to either system stimulates plant growth and thus increases the rate at which plant material may be cropped by the animals. Thus productivity per unit area is enhanced and the intensity of land utilization is increased. Intensity may be increased further by the addition of supplementary feeds eg cereals, which are the output of some other crop production system. Such a situation is illustrated in Figure 3. As the quantity of supplementary feed increases, the significance of the endogenous feed production of the system to the nutrition of the animals decreases. Eventually a point may be reached where the animals derive practically no nutrition from feed produced within the system and they become dependent entirely on the feed input to the system. The field or pond then functions as little more than an

Figure 3.

.. Fish production system with supplementary feeding.

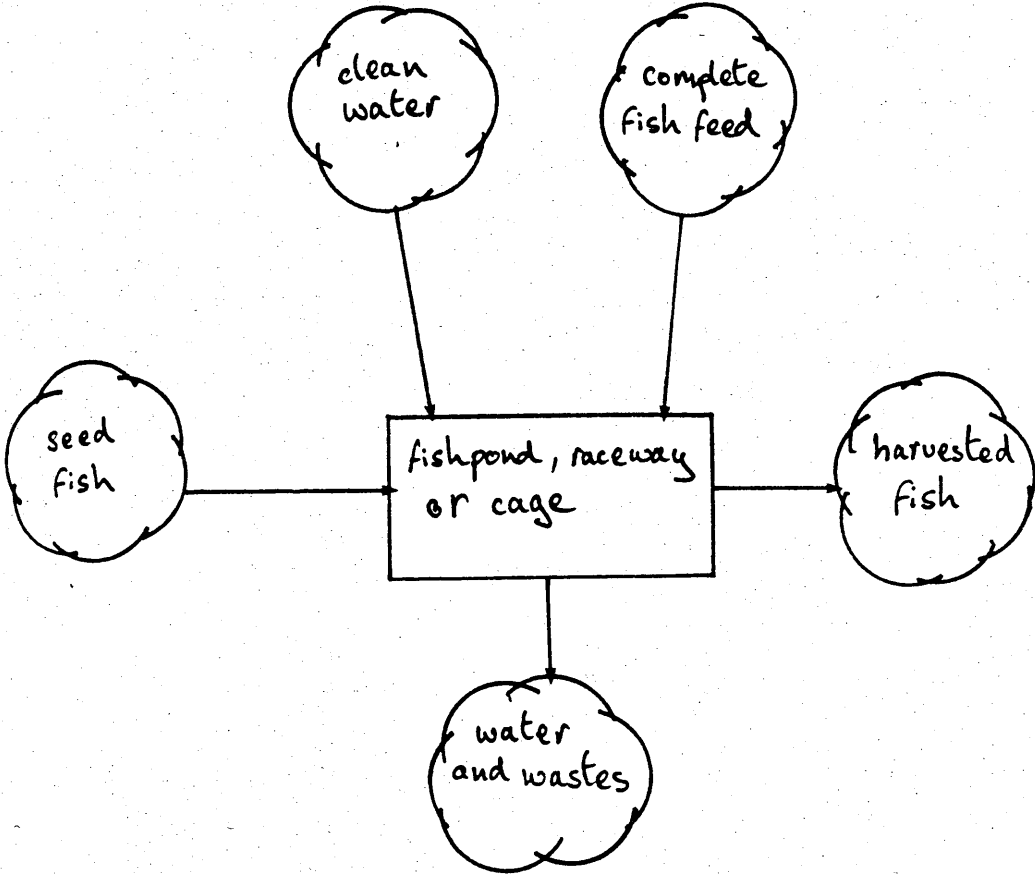


enclosure or "feedlot" within which the animals are kept and fed, and the animals within the system function simply as converters of feed into animal products. In this situation the rate at which waste products are excreted by the animals usually exceeds the rate at which they can be recycled by natural processes within the system, and some provision has then to be made for their removal. In systems of fish culture this is done by exchanging the water in the pond usually by having a continuous flow of water through it.

Figure 4 outlines a typical intensive fish culture system. Since the fish are no longer able to select some of their feed from natural sources, care must be taken to ensure that the feed input to the system is nutritionally complete so that no nutritional deficiency arises in the fish. This situation is analagous to other systems of intensive animal production, such as those of pigs and poultry.

Figure 4.

Typical intensive fish culture system.



1.3. Comparing systems of animal production - relevant efficiency criteria.

It is now fairly well accepted that if we are to increase or even maintain the food supply to a growing world population, some reduction in the amounts of animal products consumed in the developed world will have to take place. This argument has been made by many authors including Leach (1973) Pimentel and Pimentel (1979). Leach suggests that;

"..if the goal of a high quality diet for all is to be met either world energy supplies must be greatly increased, or they must be shared more equitably, or what is meant by a high quality diet must be redefined, eg fewer animal products, or food producers must learn to achieve high yields with low energy inputs. The last two options seem the most likely and possible. It is interesting to note that several development agencies including FAO, have recently begun to accept them."

Pimentel and Pimentel state that;

"Currently an estimated fifty one million tonnes of plant protein suitable for man is fed to the world's livestock. This represents forty two percent added (additional) protein that would be available to the world population if a change to vegetarianism were made in the future."

they go on to point out however that;

"..just as livestock production is vital to man today it will be important to him in the future. Cattle, sheep and goats will continue to be of value because they convert grasses and shrubs on pastures and rangeland into food suitable for man. Without them man cannot make use of this type of vegetation."

Similar arguments have been made related to the food supply prospects of the UK. Mellanby (1975) has argued that a substantial decline in the amounts of animal products consumed would be necessary if Britain were to become self sufficient in food supplies, and Holmes (1977) has argued that such a strategy may be necessary in the short term if our economic troubles persist. It is recognised however that animals will still have roles to play in food production because they are able;

(a) to convert resources that are unavailable or unsuitable for direct human consumption as food,

and

(b) to collect and concentrate resources from land that cannot conveniently be cropped by other means.

Even accepting that animals will continue receive substantial quantities of high quality feed, that could be used directly as human food, there is a strong case for allotting these feeds to the animal production systems that make the most

efficient use of them. In order to identify those systems of animal production which make the most efficient use of the resources available it is necessary to develop measures of efficiency by which they may be compared.

Spedding (1973) defines efficiency as;

"...a ratio of units, usually functionally related, generally equivalent to a rate."

and states that;

"The ratio Output/Input exemplifies this relationship and appears appropriate for all processes, whether a product is involved or not, provided that time is accepted as an input."

Animal products such as meat, fish, eggs and milk are valued mainly as sources of protein in the human diet, although substantial quantities of dietary energy are also derived from them. The protein obtained from each of these products is generally of similar quality, in terms of human dietary requirements, and of higher biological value than protein of vegetable origin. Additionally most humans find animal protein sources more palatable than vegetable protein sources. It seems reasonable then, that when formulating efficiency criteria by which to compare the efficacy of various systems of animal production that protein production should be taken as the numerator of the efficiency ratio as this is the product with which we are most concerned. The choice of the denominator is less straightforward.

If we are simply concerned with comparing the feed conversion efficiency of different animals then some measure of feed intake might be suitable as the denominator of the efficiency ratio, eg the amount of crude protein consumed or the amount of metabolizable energy consumed. These units are appropriate if the nature of the feeds consumed by the different animals is similar. Difficulties arise however when the nature of the feeds consumed varies considerably. Thus, ratios of protein to crude protein or metabolisable energy consumed are usually acceptable measures for comparative purposes for animals on cereal based diets but would be inappropriate for comparing pigs on a cereal based diet with cattle on a grass diet. Although the products are similar, in nutritional terms the resources on which they are based are rather different. In such a situation a more useful comparison might be between the efficiencies of protein production per unit of land used to produce the feed. As Duckham, Jones and Roberts (1976) have pointed out, land is a finite resource which represents a net by which we may trap solar energy which is by far the most important source of energy available to us, and;

".. there are increasing demands for land for uses other than gathering and converting solar energy into materials to be consumed by man. Consequently land is a major resource that should appear in the denominator of efficiency in any long term consideration."

Using land as the denominator overcomes the problem of comparing animal production systems that are based on different feed resources, but raises another problem in that land varies in quality. Table 3 from Holmes (1981) shows a comparison of typical levels of edible protein production from one hectare of land. It can be seen that the production of eggs, poultry and pigmeat based on cereal concentrates produced from one hectare of arable land is higher than the production of beef or lamb from one hectare of good grassland. But as Holmes (1977) points out;

"These figures over-simplify the comparisons. Beef cattle and sheep can utilize grazing lands of low productivity. In such circumstances the production per hectare might be lower but the alternative uses might be waste or amenity land. Cattle and sheep can also utilize by-products on arable farms and industrial by-products and so may raise overall productivity."

It is important therefore to make sure that the resources on which any efficiency calculations are based are truly comparable.

Another aspect to be considered when comparing the efficiencies of animal production systems is their support energy cost. This is especially true when considering the efficiency of land utilization, as the productivity of an area of land can be manipulated by inputs of fertilizers and

Table 3.

Comparison of typical levels of edible protein production per
hectare from crops and farm livestock (UK).
After Holmes (1981).

Product.	Edible protein (kg.)
Wheat	570
Potatoes	600
Cabbage	580
Milk production	140
Milk and Beef	120
Beef from dairy cows	70
Beef from suckler cows	35
Sheep meat from ewes	35
Pig meat	90
Broiler chicken	140
Egg producing chicken	140

Note :- land differs in quality, some can produce crops, some can only be utilized through livestock. (Source Holmes, 1975; 1977.)

other factors that have a support energy cost, (support energy may be defined as any energy input not directly derived from solar radiation). The significance of support energy inputs to food production becomes more important as the monetary value of fossil fuels rises in real terms. In the long run the systems of food production that make the most efficient use of support energy are those that are likely to become the most economically efficient.

It appears then that no single measure of efficiency is appropriate for comparing all systems of animal production. Furthermore, even when a single measure of efficiency is useful for comparison of two systems that are based on similar resources, there are dangers inherent in any attempt to maximise the efficiency of use of one resource without regard for the effect that this may have on the use of other resources. As Duckham et al. (1976) state;

"..the maximization of a selected efficiency frequently results in the reverse effect on other equally valid measurements of the efficiency of the same process."

In this study several measures of efficiency will be used depending on the animal production systems being compared and the resources on which these these systems of production are based. For instance the conceptual similarity between extensive systems of fish culture in ponds and ruminant grazing systems has been referred to in (1.2). When comparing these systems, protein production per unit area of land would

appear to be the most relevant efficiency criterion as land is the major resource being utilized. But when comparing more intensive systems of production, in which feed is the dominant input to the systems, some measure of feed conversion efficiency is probably more appropriate as the use of land is implicit in most forms of feed production. The efficiency of support energy use will be taken into consideration in all comparisons.

1.4. Fish culture systems compared with other systems of animal production. (The arguments for the investigation of fish culture in the UK.)

In terms of the criteria discussed in section (1.3) there is a good case to be made for adopting some systems of fish culture as a means of producing protein for human consumption in the UK.

1.4.1. Feed conversion efficiency of fish.

In general, fish have better feed conversion efficiencies than mammals in terms of edible protein produced per unit feed energy. This is because, being poikilotherms fish expend no energy in thermoregulation. Neither do they expend energy in supporting their bodyweight (Bardach, Ryther and McLarney, 1972). One of the most significant effects of this feature of fish is that very little feed has to be supplied to fish that are being overwintered at low temperatures. This is in stark contrast to overwintering of mammals which require substantial amounts of feed merely for maintenance. However the low dietary energy requirement of fish is somewhat counteracted by their high dietary protein requirements. Intensively reared trout for instance require a diet that comprises approximately fifty per cent protein,

while in contrast growing pigs require only about twenty per cent protein in their diets. It is considered therefore that the efficiency of protein conversion by fish is more relevant to this study than the efficiency of dietary energy use for protein production.

The protein conversion efficiency of intensively reared trout has been calculated (see introduction) and found to be around twenty per cent. When this figure is compared with the figures for other systems of animal production, shown in Table 1, it can be seen to be on a par with those of pig and poultry rearing systems which range from fourteen to twenty-two per cent. If one is concerned with allotting protein feeds to those animal production systems that make the most efficient use of them, then there is obviously a case for considering the allocation of protein feeds to intensive fish rearing systems, as well as other systems of animal production. It should be borne in mind that the figures presented here compare the efficiencies of rearing trout as single animals with other livestock as breeding populations. But as Large (1976) points out, the costs of reproduction of fish are negligible compared with those of rearing them, because of the vast numbers of offspring produced by one pair of parent fish.

1.4.2. Efficiency of land utilization. (Edible protein production per hectare.)

There is considerable evidence that when fish are raised in ponds as an integral part of an agricultural system, using manures and other organic residues as feed inputs, that the production of protein per hectare of pond (surface area) is comparable with and in some cases exceeds that from ruminant grazing systems. Table 4 shows the yields of edible fish protein obtained in various pond culture systems in different countries. Edible protein has been estimated as ten per cent of the liveweight of the fish. The only feed inputs to the systems referred to are animal manures or other types of fertilizer.

With the exception of the first example shown in Table 4, which refers to an outdated European system of carp production, all the other examples show levels of protein production per hectare that are equivalent to or exceed the estimates made by Holmes (1977) for protein production from ruminant grazing systems on good grassland (shown in Table 3). The last five examples (8-12) show production levels that exceed those from egg, broiler, pork or milk production. However these five examples are from areas that have climates that are considerably different from that of the UK, and so are not really suitable examples for comparison. They are included in order to give an indication of the high levels of protein production that are possible from manure based fish

Table 4.

Edible protein per hectare of fish pond.

Input	Fish spp.	Edible protein kg/ha/yr	Location
1) Annual manure	common carp	7.3-14.1	E/C Europe
2) Frequent manure	" "	17.3-76.6	" "
3) Clarified sewage	" "	47.2	Germany
4) Duck excreta	c.carp & carp/tench	41.7 50.4	E/C Europe
5) Inorganic fertilizer	c.carp	47.7-51.8	Poland
6) Clarified sewage	" "	58	UK
7) " "	" "	18-85	UK
8) Poultry excreta	tilapia	230	C.Africa
9) Sewage	carp/poly.	280	Israel
10) Pig excreta	" "	290-380	USA
11) Cow slurry	" "	490	Israel
12) Duck excreta	" "	1,000	" "

References: (1)(2)(4)&(12) Wohlfarth et al 1979 (3) Nair 1944 (5) Szumiec 1976 (6) TWA 1981 (7) Noble 1975 (8) Nugent 1978 (9) Schroeder & Hephher 1976 (10) Buck et al 1976 (11) Allen & Hephher 1976.

culture under certain conditions. To put these figures into a world context, it is useful to compare them with the protein production per hectare of soya beans, which can yield more protein per hectare than virtually any other crop (Table 5).

The first five examples of fish culture yields in Table 4, are from European countries that have comparable climates to that of the UK, and show the levels of production that could be expected from manure fed fish ponds under UK conditions. Examples (6) and (7) show extrapolated yields obtained in the UK from experiments in raising fish in tertiary treatment sewage lagoons. These results show that it is reasonable to expect that similar yields, to those obtained in Europe, may be obtained in the UK from similar systems of production.

In making a comparison between the productivity of manure based fish ponds and that of ruminant grazing systems it should be noted that Holmes' figures relate to protein production from beef and sheep grazed on good quality grassland. Fish ponds however may be constructed on land that is of poor agricultural quality. As Macan, Mortimer and Worthington (1942) point out;

"Land that is too water-logged or too poor for agricultural purposes may be profitably flooded and, with suitable treatment, made to produce a good crop of fish."

Mantle and Lawson (1980) calculated that the average

Table 5.

Soya bean production

Country	Yield kg/ha/yr(av.)	Edible protein kg/ha/yr*
USA	2162	865
CHINA	904	361
JAPAN	2000	800
BRAZIL	1360	544
WORLD	1660	664

References: FAO 1979, McDonald, Edwards and Greenhalgh 1966.

*Edible protein at 40% DM.

production of edible protein from grazing beef cattle in the UK is about 31 kilogrammes per hectare per year, and Worthington (1940) quotes figures for meat production from the poorest Nardus grassland at 5 pounds per acre (5.6 kg/ha/yr.) and from the best Lincolnshire pastures at 250 pounds per acre (280 kg/ha/yr.). Taking the edible protein content of a beef carcass at fifteen per cent (Homb and Joshi 1973) then Worthington's figures for edible protein from grazing cattle are 0.84 kg/ha/yr. and 42 kg/ha/yr. respectively. It can be seen then, that the protein yields that may be obtained from manured fish ponds compare very well with those obtained from grazing ruminants on average quality grassland.

1.4.3. Efficiency of support energy use.

Table 6 shows the energy ratios for protein production of a variety of animal products. From this table it can be seen that the energetic efficiency of trout production in the UK is lower than that of other forms of animal production. That trout production has a lower energetic efficiency than marine fishing is not surprising as trout farming is currently dependent on marine fishing for approximately fifty per cent of its feed requirements. As Edwardson (1976) points out, these figures highlight the paradox of catching fish to feed farmed fish. Thus, while intensive trout farming may be as efficient as other methods of animal production in terms of feed conversion, it is not so in terms of its energetics. In

Table 6.

Support energy ratios for protein production.

Product	Energy Ratio MJ/kg Protein.	Reference.
Trout(UK,feed)	389	Edwardson 1976
Fish(UK,total P)	355	Leach 1976
Eggs(battery)	353	" "
Pigs and poultry (whole farms)	316	" "
Broilers	290	" "
Carp(Germany) (feed+fert.)	250	Edwardson
Milk	208	Leach
Cattle&sheep (whole farms)	185	" "

contrast carp farming in Germany (based on inputs of cereals, lupins and inorganic fertilizers) has a much more favourable energetic efficiency which is of the same order as other forms of animal production.

1.4.4. The roles of fish in agricultural systems.

When fish are raised in ponds, that are constructed on land that is of poor quality for other agricultural purposes eg because of water logging or propensity to flooding, they are able to act as collectors and concentrators of resources from land that cannot be conveniently cropped by other means. Phytoplankton, zooplankton and other animalcula, are produced in ponds as a result of their natural, or enhanced (by fertilizers) fertility. These organisms serve both directly and indirectly as food for the fish which collect them from around the pond and concentrate them into fish flesh.

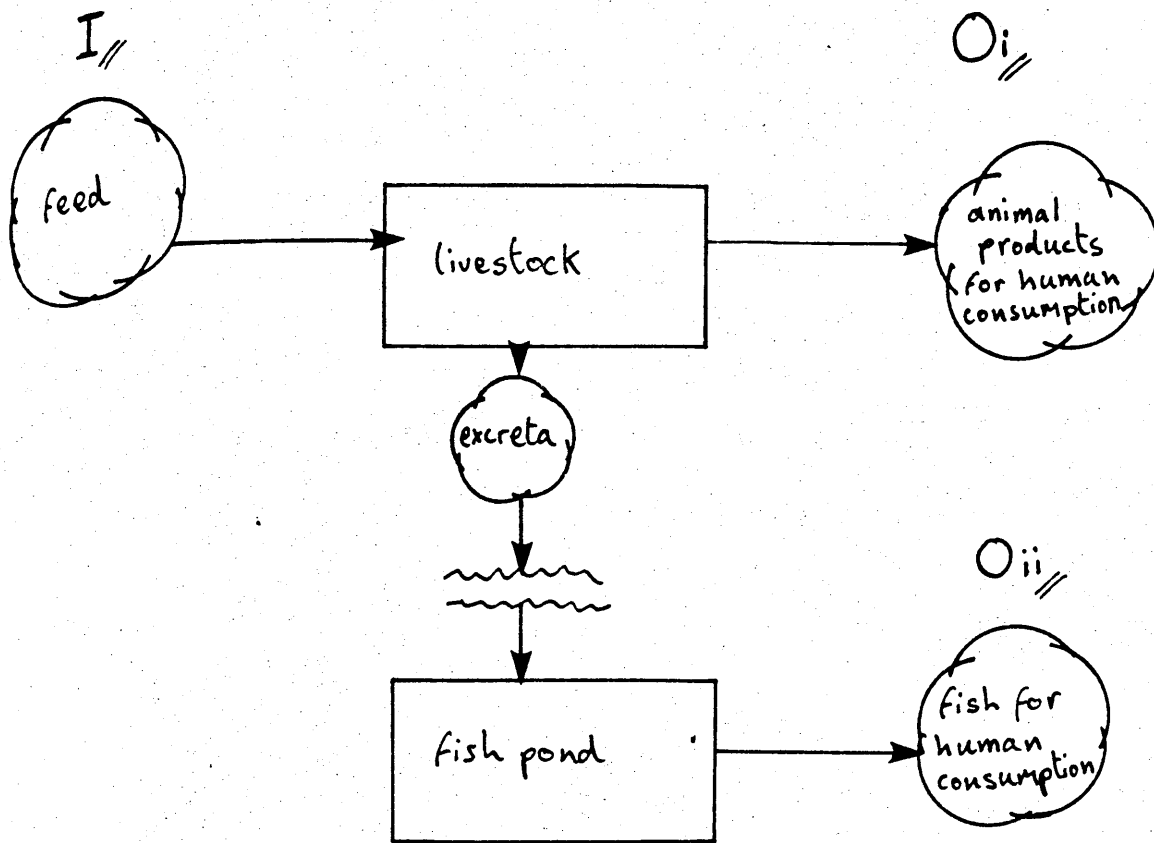
In addition to collecting and concentrating resources from a pond, fish in ponds are able to convert a wide range of agricultural wastes and by-products, that are not suitable as human food into fish flesh which is. Table 2 showed some of the fish feeds used in China in the early part of this century. A similar range of materials is still used in China (FAO 1977). While some of these materials could be used as human food, they are often considered unpalatable, and thus only suitable for use as animal feeds. Many of the materials fed to fish, such as animal and human excreta are in no way

suitable for direct human consumption. The feeding of these materials to fish results in conservation of nutrients that might otherwise have been wasted.

The efficiency with which livestock feed is converted into human food may be raised by the feeding of animal excreta to fish in ponds. This is because an additional product is being generated from the same feed input. This concept is illustrated in Figure 5.

Figure 5.

Increasing the efficiency of food conversion by integrating livestock and fish production.



$$E_i = \frac{O_i}{I} < E_{ii} = \frac{O_i + O_{ii}}{I}$$

1.5 The hypothesis under consideration.

This study investigates the hypothesis that; the introduction of fish culture in the UK as an integral part of the UK farming system would result in an increase in the efficiency of utilization of certain classes of agricultural land and other biological resources, which are under-utilized or wasted at present.

In order to investigate this hypothesis it is necessary to find out :

- (a) what systems of fish culture are operable under UK conditions,
- (b) what the potential productivity of these systems would be under UK conditions,
- (c) what resources would be required to construct and operate these systems,
- (d) whether these resources are available or could be made available,
- (e) what the efficiencies of resource use would be compared to alternative systems of using the same resources,
- (f) what changes in food chain efficiencies would result from the adoption of integrated livestock and fish rearing systems,

(g) whether the products of pond fish culture systems would be both acceptable and marketable to consumers.

These points are addressed in the remaining sections of this study.

Chapter 2.

The range of pond fish culture systems.

Several authors have made analogies between fish culture and terrestrial agriculture, including Taverner (1600), Macan et al (1944), Mortimer and Hickling (1954) and Reay (1979). Conceptually there is little difference between farming water, aquaculture, and farming land, terrestrial agriculture. In both cases the harvested products are derived either directly from photosynthesis, plant materials, or indirectly, animal products. The ultimate limit on the productivity of both aquatic and terrestrial environments is thus the amount of sunlight that falls on a particular area of water or land.

In practice however, there is a considerable difference in the way the two types of environment are exploited. Consider the analogy made in 1.2 between ruminant grazing systems and fish culture systems. In the production of beef from grassland the cattle feed almost exclusively on primary products, ie grass and associated herbage such as clover, any secondary production, eg of insects which feed on cattle excreta, remains unused. Thus only one ecological niche is

exploited and animals which fill other niches are either deliberately excluded or at least ignored.

In contrast to this, several species of fish which are adapted to different niches, have different feeding habits and are able to exploit several different feed resources, may be stocked in the same pond. For instance in an association of species commonly used in China, grass carp, silver carp, bighead carp, mud carp and common carp may be reared together in the same pond. These species occupy different strata of the water and have different feeding habits. Grass carp feed mostly on macrophytes throughout the water body, silver carp feed on phytoplankton and bighead feed on zooplankton both usually near the top of the water column, whilst common carp and mud carp tend to be bottom feeders which consume detritus, zooplankton and benthic organisms.

This association of species or polyculture, is rarely applied in terrestrial agriculture. Probably the best parallel is that of game ranching, where several species of herbivores of different sizes and feeding niches are stocked together and exploit vegetation growing at different levels eg grass, shrubs, and trees.

The advantage of polyculture is that it allows increased exploitation of the natural feed production of the water

body. It is thus a management factor that can be manipulated and used to vary the intensity at which systems of fish culture are operated. It should be noted however that the advantages of polyculture apply only to systems of fish culture in ponds, ie standing water, in which all or a major part of the fish feed is derived from the natural productivity of the water body. In moving water systems of fish culture, where the fish are entirely dependent on a nutritionally complete feed input to the system, this advantage does not apply. These two systems of fish culture are entirely different. The remainder of this study concentrates on systems of fish culture in standing water ponds.

2.1. Spectrum of intensity of fish culture in standing water ponds - compared with other systems of animal production.

The basic components of any system of animal production are the animals that are being raised and the feed that is available for their nutrition. It is the rate at which feed is supplied to and utilized by the animals that determines the system's productivity. Both the rate of supply of feed and its utilization are dependent on several factors.

The availability of feed for the animals is a function of

- (a) the rate of production of natural feed within the system,
 - (b) the rate of input of supplementary feed to the system
- and
- (c) the rate at which the feed is consumed.

These in turn are dependent on other factors, thus:

- (a) the rate of production of natural feed, is a function of the fertility of the system and prevailing edaphic conditions, eg temperature and sunlight, (and possibly interaction with the grazer).
- (b) the rate of input of supplementary feed, is a management function,

and

(c) the rate at which feed is consumed, is a function of feed availability, animal size, stocking rate and appetite, which in turn may be a function of edaphic conditions.

The rate of feed utilization is a function of the rate of feed consumption (c) and feed quality.

While edaphic conditions are not easily controlled (ie without substantial investment in housing etc, which is considered to be outside the scope of this study) fertility, supplementary feeding, animal size and stocking rate are all manipulable and thus constitute management functions which may be used to alter the intensity at which animal production systems are operated.

In their most extensive forms, animal production systems involve stocking an area of land (or water) with young animals, letting them feed off the natural productivity of that area and cropping them when they have grown to suitable size. Some increase in intensity may be afforded by manipulation of the animal stock, to ensure that the standing stock at cropping time is matched to carrying capacity. Intensity may be further increased by manipulation of other management factors, ie by fertilization and feeding.

Thus three main management controls affect the intensity at which any system of animal production is operated. In terms

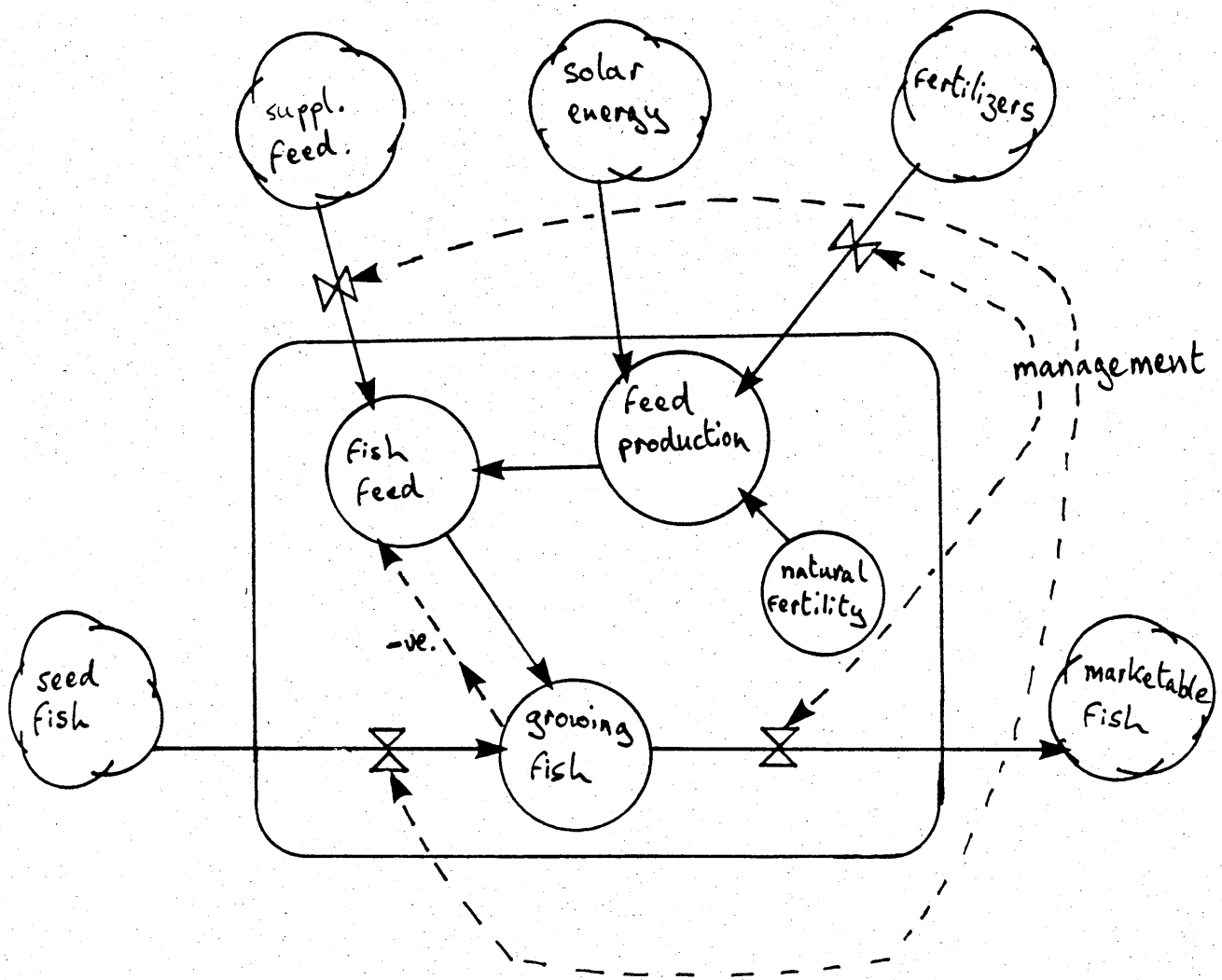
of fish culture in standing water ponds, these controls may be expressed as;

- (1) Control of fish stocks (biomass per unit area)
- (2) Control of pond fertility
- (3) Control of supplementary feeds.

Figure 6 is a schematic representation of a standing water fish culture system. It shows the influence of management controls on the system. Fertilizers, natural fertility and supplementary feed affect the amount of available fish feed positively which has a positive effect on the growing fish. The greater the biomass of fish, however, the greater the rate at which they reduce the availability of feed, this is then a negative effect. Therefore as fish biomass is increased, by addition of more "seed" fish, beyond a certain point (the natural carrying capacity of the pond) feed and or fertilizers must be added to the system if fish yields are to be increased.

Figure 6.

Influence of management on fish culture in ponds.



2.1.1. Control of fish stocks.

The fish stock in a pond is determined by two factors, the stocking rate (number of fish per hectare) and individual fish size (kilogrammes per fish). The product of these factors gives the fish stock or biomass (kilogrammes per hectare).

As long as the quantity of available feed in a pond is equal to or exceeds the nutritional requirement of the fish stock, then maximum growth will take place. Increases in fish stocks to a point where feed requirements exceed supply will lead to a diminution of individual fish growth. Once the feed supply is sufficient only to meet the maintenance requirements of the fish stock, then growth will cease altogether. The standing stock of fish in a pond at this point is the "carrying capacity" of the pond.

Although small fish have a larger feed requirement per unit weight than large fish, because of their higher maintenance requirement per unit weight, in practice the difference is insignificant and so carrying capacity is the same for small and large fish. This is probably due to the ability of a large number of small fish to exploit the natural feed supplies of a pond better than a small number of large fish, (Hepher 1972).

Hepher (ibid.) states that;

"In spite of its importance for fish production in ponds, no satisfactory method has been developed as yet for determining the amount of natural food produced in the pond and available to the fish."

It is therefore impossible to deduce the carrying capacity of a pond except by observation and experience. Stocking rates for fish ponds must therefore be estimated in the same manner. As Hephher (ibid.) points out;

"Empirical experience has taught fish farmers what the stocking rate must be in order to obtain maximum yield on natural feed alone."

In practice stocking rates are usually determined by dividing the estimated carrying capacity of a pond by the market size of the fish required at the end of the production period. The size of the seed fish is determined from knowledge of individual growth rates that can be achieved in that period. For example, under European conditions C2 carp, that is carp of two summer's growth, will weigh 250-300 grammes, and C3 carp will weigh about one kilogramme, which is the marketable size in much of Europe. If the carrying capacity of the production pond for the third summer's growth is thought to be two tonnes per hectare then the stocking rate is 2,000 C2 carp per hectare.

Carrying capacity can however be manipulated to some extent by control of fish stocks with respect to species

composition. Yashouv (1971) demonstrated a mutually beneficial relationship between common carp and silver carp raised in the same pond. The addition of silver carp to fertilized common carp ponds resulted both in increased total fish production and in increased common carp production with no extra fertilization. Yasouv's explanation of this effect is that the fish occupy distinct and different ecological niches. Common carp are bottom dwelling fish feeding on detritus and benthic organisms whilst silver carp are pelagic fish which feed on phytoplankton. The faeces of silver carp are partially digested plugs of phytoplankton which sink to the pond bottom and provide additional feed for the common carp. The foraging activities of the common carp stir particles of detritus into suspension and these are filtered by the silver carp along with phytoplankton and so provide additional feed.

Many other authors have shown the positive effect of polyculture on total fish yields. Spartaru (1977) states that a beneficial relationship exists between common carp and silver carp as long as available feed does not become limiting. Opuszynski (1968) found increased total yields from the addition of grass carp and silver carp to common carp ponds, without affecting the yield of the common carp themselves. He did, however, find that yields in fry ponds were reduced by such a combination of species. The reason for this effect being that the fry of all three species have

similar feeding habits. In this respect it is worth noting that the Chinese use monoculture for fry rearing until the fish reach three centimetres in length, (FAO 1977).

The data for species composition of fish stocks is again largely empirical and has been built up from years of experience in areas such as China where polyculture has been a traditional practice. As the Chinese say;

"Feed one grass carp well and you feed three other fishes."

2.1.2. Control of pond fertility.

In the introduction to "Fertilizers and Fishponds" Mortimer (1954) wrote;

"The principles of pond manuring are similar to those applied in agriculture. Production is increased by addition of certain essential "minimum substances" notably phosphorous and lime and in certain cases potassium, and by the stimulating effect of these on the growth of natural fish food. The process is largely empirical and depends on the fish farmer's judgement. Fertilizers are applied at one end of the production chain, and an increased fish crop taken out at the other, while the intermediate effects in the conversion of fertilizer to fish flesh are to a great extent unknown."

Little more is known today about the precise pathways along which fertilizers move in the food chain in a fish pond, although the effectiveness of fertilization to increase yields and thus intensity of production is unquestionable.

Between the World Wars nitrogenous fertilization was considered to be ineffective and the main emphasis was on the use of phosphatic fertilizers, lime and organic manures.

As Schapperclaus (1933) wrote;

"In spite of numerous experiments, the general effectiveness of nitrogen manures in increasing fish production has not been established. In any case it is doubtful whether the cost of these manures can be recovered in the fish crop.

Experiments at Wielenbach and elsewhere show that the best results were obtained with manures containing no nitrogen as long as organic matter was present."

In the post-War period further experiments established the effectiveness of nitrogenous fertilization, as Wolny (1966) states, there was a change in opinion from the theory of nitrogen less fertilization to the modern approach that recommends inter alia nitrogenous fertilizers. In the last decade or so, however, most experimental work on pond fertilization has been concentrated on the use of organic manures and more specifically on animal and human excreta.

Experiments to determine the relative efficacy of inorganic and organic manures appear to have been inconclusive. Wohlfarth et al (1979) cites two sets of experiments in different countries that gave contrasting results. What is clear is that similar results can be achieved from either sort of fertilizer. This being the case, there are several reasons to concentrate on the use of organic manures for controlling pond fertility. Inorganic manures are becoming increasingly expensive, as their manufacture depends on considerable inputs of support energy. Additionally the substitution of inorganic fertilizers for organic manures in agriculture has led to the accumulation of agricultural wastes and consequently problems of waste disposal and pollution. Using such organic wastes as fertilizers for fish ponds, helps to alleviate these problems, and recycles

valuable nutrients in an ecologically sound manner. Furthermore the use of organic manures as the main input to fish culture has been shown to be one of the cheapest ways of producing animal protein for human consumption, (Wohlfarth et al 1979). In China, where no inorganic fertilizers are used in fish culture, fish are the cheapest source of animal protein, (FAO 1977), (see Table 7).

While there is only one pathway by which inorganic fertilizers can enter the food chain of a pond ie as a source of nutrients for autotrophs, there are three distinct pathways by which the constituents of organic manures may enter the food chain.

- (1) As a source of inorganic nutrients for autotrophs
- (2) As a source of organic compounds and minerals for heterotrophic micro-organisms
- (3) As a direct feed source for fish. (Wohlfarth 1979).

The relative importance of each of these pathways is not known. As Edwards (1980) points out;

"It is still not understood, how much nutrition is derived by the fish from the waste itself and from the natural food in the ponds which develops as a result of the fertilizer effect of the waste."

It is fairly clear however that optimum exploitation of fertilized fish ponds requires a mixed species stock of fish. As Wohlfarth et al (1979) state;

"Rational manure utilization requires polyculture stocking

Table 7.

A comparison of the retail price of fish with other basic food commodities, in the Shanghai area of China. (After FAO, 1977.)

Food item	Retail price Yuang per kg
pork 1st grade	2.4
pork 3rd grade	1.6-1.8
vegetables	0.04
fish	0.6-0.8
chicken	2.4-3.0
duck	a little cheaper than chicken.

or at least the use of fish with a wide feeding spectrum."

In China and elsewhere in the Orient where organic manures have been the traditional management tool in fish farming for centuries, the application rates of manures seem to be guided by various "rules of thumb" and by "craft knowledge" of fish farmers built up over years of experience. Often livestock such as pigs and ducks are kept either over or in close proximity to fish ponds, so that their excreta is added continuously to the ponds. The number of livestock kept per unit area of pond has been decided upon on the basis of experience. For instance the Chinese consider 30-45 pigs to be adequate for one hectare of pond, (FAO 1977). Both Hoffmann (1934) and Lin (1940) refer to the Chinese farmer's practice of observing the colour of the pond water in order to decide whether to add more fertilizer or feed to their ponds. FAO (1977) state that the rate of organic manure application in south China varies from 5,625-10,125 kg/ha./yr. applied in three portions the first larger than the last two.

Wohlfarth (1978) states that;

"The amount of manure used and the frequency of application are probably more critical than the source of manure."

He goes on to show the tremendous variation in the frequency of manuring reported in the literature. In Europe the traditional method of manuring was to spread or heap manure

on the pond bottom during the spring before filling the pond with water. As the manure decomposed it used up oxygen and anaerobic conditions developed, which sometimes led to fish kills. Woynarovich (1976) developed the "carbon-manuring technique" during the 1950's in Hungary. He states that;

"The basis of this technique is that when soft fresh manure is mixed with pond water and repeatedly spread over the entire surface of the pond, carbon compounds are released which lead to a continuous high primary production.

When ducks distribute their droppings in a pond they are living "carbon-manuring machines". Poultry droppings or pig manure has to be distributed continually at very short intervals preferably in a fresh condition because its carbon content is highest at this stage (some farms in Hungary distribute the manure five times a week). Using the carbon-manuring technique, very large quantities of manure can be spread in a pond (30-60 tons/ha./100 days). This also avoids environmental pollution. The pond water receives well distributed manure without any trace of odour and converts it, through the natural food chain into fish flesh.

A fat pig produces about 1.6-1.8 tons of manure (including urine) per year on average. This means that the fresh manure of 15-25 pigs can be used on a one hectare pond."

By applying this technique to carp ponds in Hungary Woynarovich increased yields from 141 kg/ha./yr to 766kg/ha./yr. (Wohlfarth et al 1979).

2.1.3. Control of supplementary feeds.

Supplementary feeds are feeds added to a fish pond to supplement the natural fish feed production of the pond. The quality and composition of supplementary feeds to intensify pond productivity depends on two factors;

- (a) The availability of natural fish feeds
- (b) The nutrient requirements of the fish.

The factors affecting (a) and (b) have been discussed above and it has been shown that natural feed availability can be manipulated by the use of fertilizers and that an increase in fish biomass in the pond results in an increase in demand for feed. As long as the feed demand of the fish is met by the natural feed supply then there is little advantage in supplementary feeding as maximum growth will take place without it, except towards the end of the season as biomass approaches carrying capacity. However it is possible to increase the carrying capacity of a pond by supplementary feeding.

Hepher (1972) outlined the principles behind the supplementary feeding of common carp with carbohydrate feeds. Analysis of chironomid larvae, which are a major source of natural feed for carp, showed that carp may derive as much as sixty percent of their feed energy from the protein content of natural feeds. Carp do however have considerable ability to digest carbohydrate, and thus their energy requirements for metabolism can be satisfied by

supplementary carbohydrate feed, such as cereal grains. As Hephher (ibid.) states;

"That part of the protein that would have been used for catabolism is thus replaced and used for further growth. One can observe an interesting phenomenon whereby, feeding cheap carbohydrate feed, a high value and more expensive fish protein is produced. This, of course is only the apparent effect, which actually is brought about by nutritionally balancing the natural food and its better utilization by the carp. Nevertheless, it is an important advantage of the carp as a pond fish."

When the biomass of fish in a pond passes a certain point, the natural feed becomes insufficient to supply the protein needs of the fish. It then becomes necessary to increase the protein content of the supplementary feed. In standing water ponds, natural feed still remains a significant input to fish nutrition even at very high stocking rates, because of its constant production from the fertilization by fish excreta. Furthermore the larger the number of fish the better they exploit the natural feed resources of a pond.

A great variety of organic materials are used in supplementary feeding of fish, including cereals and cereal by-products such as wheat and rice bran, oilseeds and presscakes, food processing wastes and residues, and animal products such as fish meal and blood meal. There is

sometimes a confusion in terminology in the literature and some of these materials have been referred to as organic manures.

In China by far the most important supplementary feeds are grasses and other vegetable matter which are used to feed grass carp. The area required for growing grass to feed the fish is reckoned to be ten per cent of pond area, thus the banks of the ponds can be used effectively for feed production. Cereals and oilseed by-products account for less than one per cent of the feed input to ponds. Fish other than grass carp derive their nutrition from the natural feed production in the ponds which is stimulated by fertilizers and grass carp faeces, (FAO 1977).

2.2. The Israeli experience - A Sino-European synthesis.

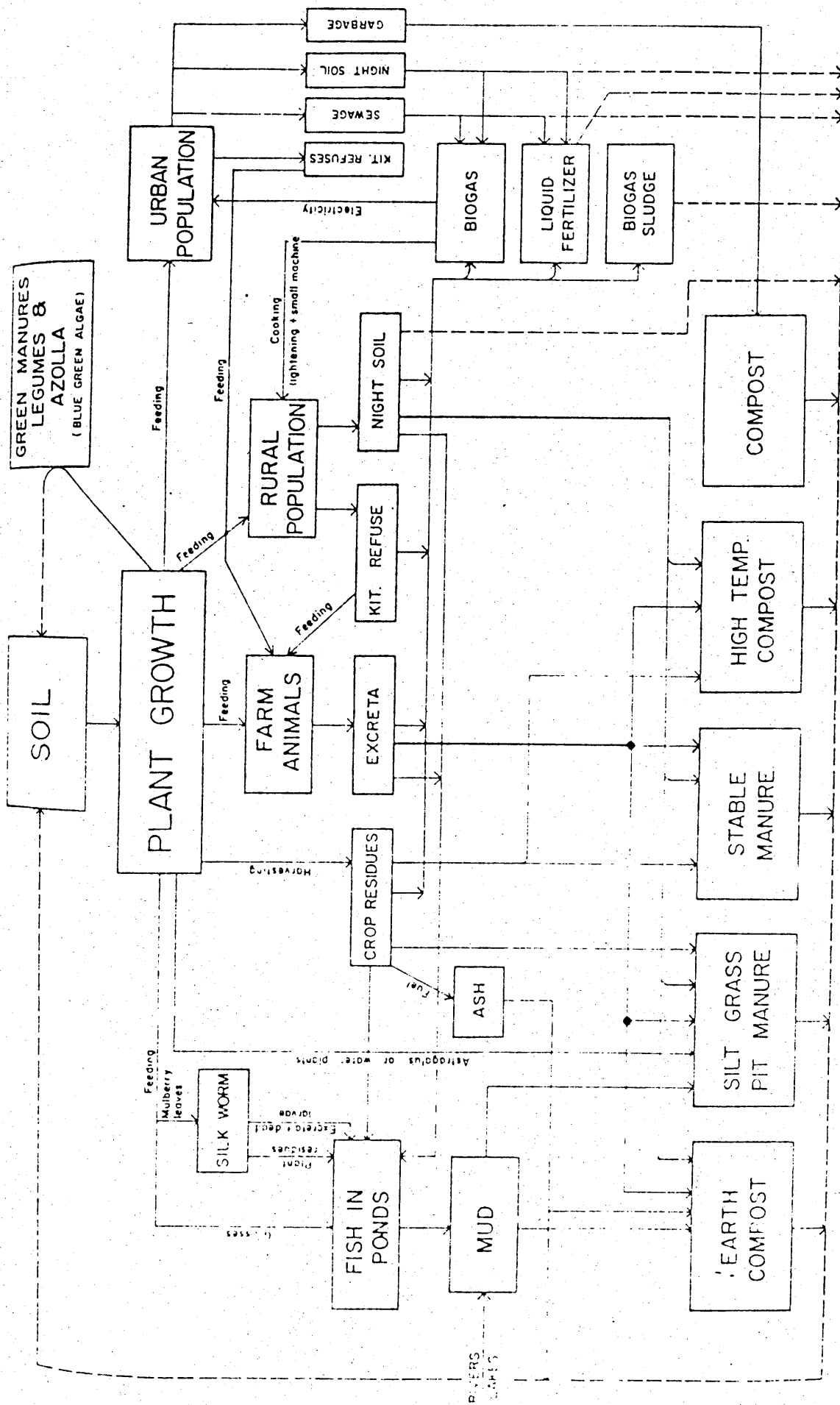
Fish culture in China is a component of an integrated agricultural system. Wastes and by-products of one agricultural enterprise are used as inputs to other agricultural enterprises. Figure 7 shows the extent of this integration.

"To the Chinese there is nothing like waste; waste is only a misplaced resource which can become a valuable material for another product." (FAO 1977ii).

Some two thirds of the total nutrient input to Chinese agriculture is derived from organic sources. From Figure 7. it can be seen that fish culture is both a user and producer of organic manures. Optimum use of organic fertilization of ponds is ensured by polyculture, and accumulated organic detritus (pond mud) is periodically excavated to provide manure for arable crops. Because Chinese agriculture is based on principles of total integration and organic recycling, agricultural waste disposal and pollution problems, are less serious than those encountered in Western agriculture in recent years.

Israeli agriculture, in contrast, is based largely on the Western model, that is with discrete agricultural

Figure 7.
FAO (1977)ii.



RECYCLING OF ORGANIC WASTES IN THE PEOPLE'S REPUBLIC OF CHINA

enterprises. Commercial fish culture was based until recently on common carp monoculture and supplementary feeding. Nowadays, however, this situation is changing and polyculture of chinese carp and tilapia is replacing the monoculture of common carp, and a wider utilization of human and animal wastes is beginning to replace and supplement traditional fish feeds, (Edwards and Densen 1980).

Wohlfarth (1978) summarises the development of manure based fish culture in Israel since 1974. A kibbutz neighbouring the "Fish and Aquaculture Research Station" at Dor, Hof-Carmel, was having problems disposing of the manure output of their large cattle herd. The kibbutz also had a large area of fish ponds (170 ha.) and enquired of the research station whether the manure could be disposed of in the fish ponds. The research station was already interested in polyculture of Chinese carp and it began to experiment to see whether manure could be used effectively to replace conventional fish feeds. Figure 8 summarises the results.

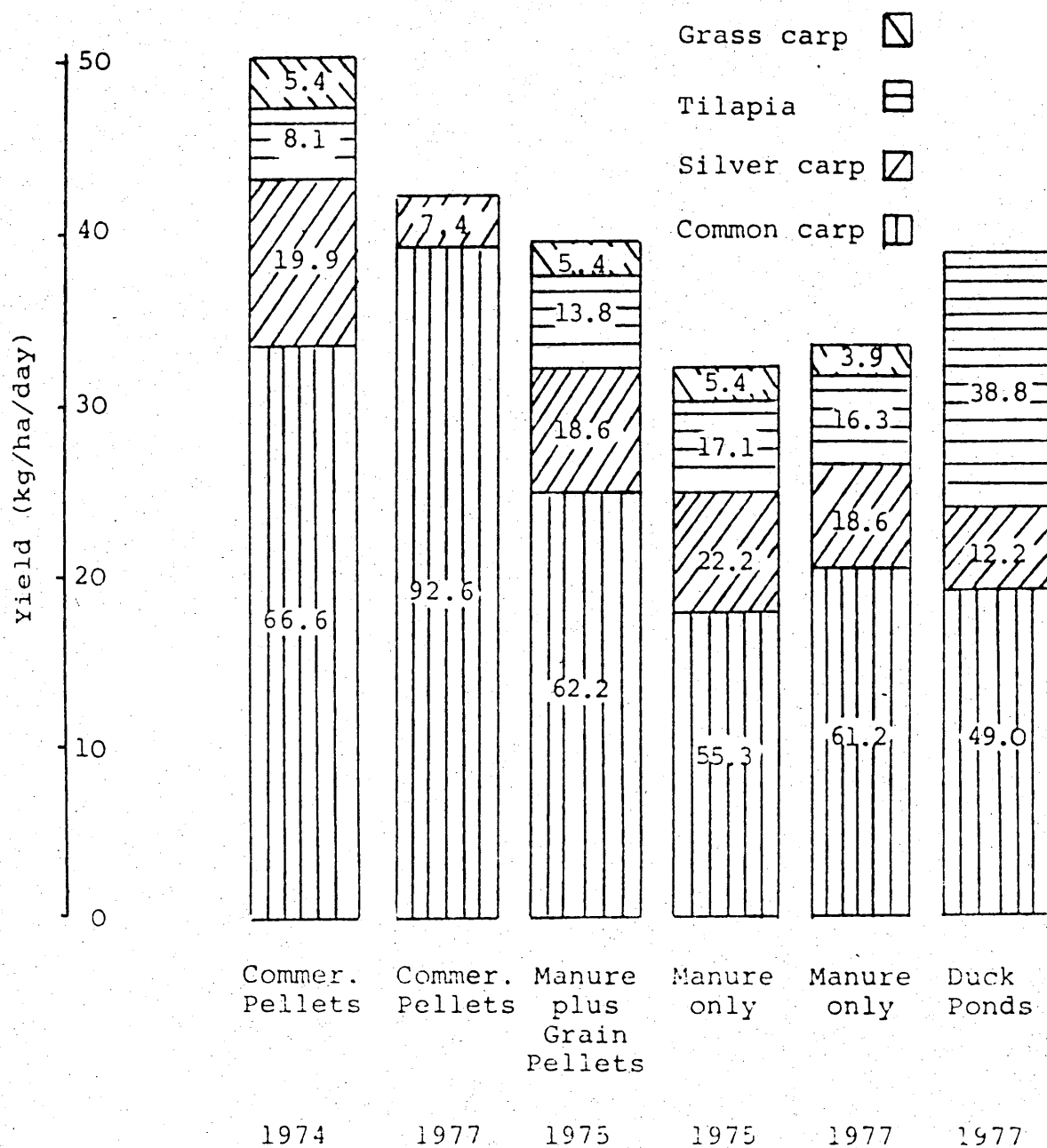
In their initial experiments with manure applied at a constant rate the research team found that although at first fish growth was very fast, after a while it tailed off. They then found that by treating the manure as a feed and increasing the rate of application with increasing fish biomass, fast fish growth could be maintained. Overall mean manure conversion ratios (ie manure D.M. : fresh fish

weight) are said to be around 3.5 : 1..

From Figure 8 one can see that yields from manure based polyculture are two thirds of those from a commercial pellet (25% protein) based poly culture and three quarters of those from a pellet based monoculture of common carp (with a few silver carp to control phytoplankton blooms). Yields from manure and grain feeding and from duck ponds were similar and not markedly different from pellet-based monoculture.

It is interesting to note the increased yields from polyculture even in pellet-fed ponds. Although Wohlfarth does not refer to this, it seems to confirm Hepher's (1972) observation that natural feed remains significant even at high production rates, and the better ability of polycultures of fish to exploit this compared to monocultures.

Figure 8.
Wohlfarth (1978)



Yields of ponds with feed and/or manure

Chapter 3.

Biological efficiencies of various systems of fish culture in standing water ponds.

The biological efficiencies of two basic types of fish culture system are calculated. The efficiencies with which resources are used within these systems are compared with the efficiencies with which they might be used in alternative systems.

It has been necessary to make some data assumptions as the data given in the literature, on which these calculations are based, are insufficient in some respects. These data assumption are given in Table 8.

Table 8.

Data assumptions for efficiency calculations.

<u>Product</u>	<u>Parameter</u>	<u>Value</u>
1) Wheat	Crude protein content.	10% at 85% D.M.
2) Wheat	Av. UK yield	4,900 kg/ha/yr.
3) Fish (farmed)	Edible protein content	10% (fresh wt.)
4) Pigs (av.)	Killing out	75%
5) " " "	Edible protein as % carcass wt.	10%
6) " " "	Edible protein as % live wt.	7.5%
7) " " "	Protein conversion E. edible protein kg/kg crude protein	23%
8) " " "	Crude protein consumed per kg live wt.	0.33 kg/kg
9) " " "	Concentrates fed per kg carcass wt.	3.34 kg/kg
10) " " "	Concentrates fed per kg live wt.	2.51 kg/kg
11) Concentrate	Production per ha per yr.	4,000 kg.
12) Cattle slurry	Available N. as % D.M.	2.5%
13) Pig excreta	D.M. output from 50-80 kg pig	0.4 kg/day
14) " " " "	Available N. as % D.M.	4%

References: 1) Mc Donald et al 1966. 2) FAO 1979. 3) Chapter 1.
 4)MLC 1981. 5) & 7) & 9) & 11) Holmes 1977. 6) 4&5. 8) 4&7. 10)
 9&7. 12) & 14) ADAS 1979. 13) Larkin, Morris, Noble & Radley 1980.

3.1. The protein conversion efficiency and protein production efficiency of supplementary feeding.

Szumiec (1976) describes experiments on ;

"Intensive farming of common carp in Poland."

These experiments were based on supplementary feeding with wheat and compounded pellets which contained two levels of protein.

Two efficiencies of wheat feeding are calculated;

E1 = Efficiency of protein conversion, and is calculated as follows;

$E1 = \text{Edible protein (EP) output} / \text{Crude protein (CP) input}$

$= \text{Net yield of fish} \times \text{EP content} / \text{Wheat fed} \times \text{CP content}$

$= \text{EP Content of fish} / \text{FCR} \times \text{CP content of wheat.}$

E2 = Efficiency of protein production per unit area, and is calculated as follows;

$E2 = \text{Edible protein output} / \text{Area to produce output.}$

$= \text{EP out} / \text{Area to grow feed} + \text{Area to grow fish}$

$= \text{Net yield of fish} \times \text{EP cont.} / (\text{Wheat fed/wheat yield}) + 1.$

The protein conversion efficiency (E1) of compound pellet feeding is calculated as a comparison.

Table 9 shows data presented by Szumiec (1976) and lists the assumptions from Table 8 which are used in making the

Table 9.

Data for calculating the biological efficiencies of intensive common carp farming in Poland.

Data from Szumiec 1976.

Experimental Results:-

Year	Feed	Net Yield kg./ha.	F.C.R.
1969	Wheat	2,513	3.5
1969	Std. pellets	2,652	3.8
1971	Wheat	2,565	4.2
1971	Std. pellets	2,748	4.1
1971	Spr. pellets	3,502	3.1
1972	Wheat	2,321	3.5
1972	Std. pellets	3,346	2.7
1972	Spr. pellets	3,762	2.2

Protein content of Standard (Std.) pellets = 25%
Super (Spr.) pellets = 40%

F.C.R. = Dry weight feed : Fresh weight fish.

Data assumptions used in calculations not given by Szumiec and taken from Table 8.

- 1) Crude protein content of wheat = 10%
- 2) Average U.K. yield of wheat = 4,900 kg./ha.
- 3) Edible protein content of fish = 10% (fresh wt.)

efficiency calculations.

The average UK yield of wheat is used in calculations, rather than the average Polish yield, because the results are compared with the efficiencies of other farm animals calculated by Holmes (1977 and 1981) on average UK data. The implicit assumption is that similar feed conversion ratios (FCR, defined as the ratio of dry weight of feed : live weight gain of animal produced by that feed) and yields would be obtained from wheat feeding of carp under UK conditions. This assumption is believed to be valid because the FCR's quoted by Szumiec for wheat are fairly poor compared with average data, on supplementary feeding, from many countries reviewed by Hepher (1972). Hepher quotes a range of FCR's from:

2.5-3.5/1

for carbohydrate supplementary feeds (cereals) fed to common carp.

Table 10 shows E1 and E2 for wheat feeding. The efficiency of protein conversion (E1) lies in the range of:

24 - 29 per cent.

If these figures are compared with those given by Holmes (1977) in Table 1 it can be seen that the protein conversion efficiency of carp under these conditions exceeds that of poultry which are the most efficient converters according to Holmes.

Table 10.

Biological efficiencies of feeding wheat to common carp.
(Data from Table 9.)

Year	Net Yield (kg)	FCR	E1	E2 (kg EP/ha/yr)
1969	2,513	3.5	0.29	89.9
1971	2,565	4.2	0.24	80.2
1972	2,321	3.5	0.29	87.3

EP=Edible Protein

The efficiency of protein production (E2) per hectare of land used to grow the feed, which in the case of fish includes the area of land occupied by the pond and used to produce natural fish feed, is in the range of :

80 - 90 kg. edible protein per hectare per year.

If these figures are compared to those given by Holmes (1981) in Table 3 it can be seen that the efficiency of carp production based on supplementary feeding of wheat is of a similar order to the efficiencies of beef production from dairy cows and pigmeat production. (Holmes's figures are based on the production of 4,000 kg. of barley based concentrate per hectare per year, which corresponds to the average UK yield of barley).

Table 11 shows E1 for compound pellet feeding of carp at two levels of pellet protein content.

The range of E1 for pellets containing 25 per cent protein is:

10 - 15 per cent

and the range of E1 for pellets containing 40 per cent protein is:

8 - 11 per cent.

Thus in terms of protein conversion efficiencies it is better to feed wheat to carp than high protein pellets. The feeding of high protein pellets to carp, particularly those containing 40 per cent protein, does however result in higher yields per unit area. This may well be justified

Table 11.

Efficiency of protein conversion E1 for compound pellet feeding
of common carp at two levels of protein content.

Year	Protein content of pellets (%)	FCR	E1
1969	25	3.8	0.11
1971	25	4.1	0.10
1971	40	3.1	0.08
1972	25	2.7	0.15
1972	40	2.2	0.11

economically if the additional revenue from the fish exceeds the additional feed cost to produce the higher yield.

These results tend to confirm Hephher's (1972) observation that at high production levels the significance of natural feed for the fish declines. Furthermore the high apparent conversion efficiency of carp fed on wheat indicates the protein sparing effect of carbohydrate supplementary feeds.

3.2 The increase in protein conversion efficiency from integrated livestock and fish culture systems.

Figure 5 illustrates the concept of increased feed conversion efficiency by feeding livestock excreta to fish in ponds. Two sets of data have been used to illustrate this concept. The first set of data are from pig with fish culture systems in Central Africa reported by Nugent (1978). Nugent's data are rather scant with respect to pig feeding, therefore various assumptions have had to be made. These assumption are listed in Appendix 2 along with data actually presented by Nugent. This appendix shows the calculation of the protein conversion efficiency (E1) of an integrated pig and fish raising system at two levels of excreta input to fish ponds (stocking rates of pigs per hectare of fish pond).

The protein conversion efficiency of the pigs alone was assumed to be :

23 per cent.

The results of the calculations in Appendix 2 show that the protein conversion efficiency of the whole system is in the range:

69 - 71 per cent,

when pigs are housed over fish ponds so that their excreta

provides feed for the fish. Thus under Central African conditions it appears that protein conversion efficiency of pig feeds may be increased three fold by integration of pig and fish raising.

While it is recognised that some fairly gross assumptions have been made in these calculations, the results do serve to demonstrate the concept of raising the efficiency with which livestock feed is converted into human food by generating an additional product from the same feed input. (see section 1.4.4).

The second set of data are from an experimental pig and fish raising system in Illinois USA reported by Buck et al (1976). The same data assumptions have been made for pig feeding. In this case the assumptions are considered to be more valid as Buck et al give details of the pig feeds used in the experiment. These feeds correspond very closely in protein content to those quoted by Holmes (1977) on whose figures the assumptions are based. Additionally, Buck et al quote the actual live weight gains of the pigs used in their experiment, whose excreta was fed to the fish ponds.

Appendix 3 shows the calculation of protein conversion efficiencies (E1) from Buck et al's data. As in the first example, two stocking rates of pigs per hectare of pond were used. The results of these calculations show that the

protein conversion efficiency of the whole system is in the range:

38 - 43 per cent. Thus under North American conditions the increase in efficiency is not as great as under tropical conditions. Nevertheless the efficiency of protein conversion is increased by a factor of one and three quarters.

3.3. The increase in the efficiency of protein production per unit area from integrated livestock and fish culture systems.

The pig feeds used in Buck et al's experiment were based on concentrate composed of approximately ninety per cent maize meal and ten per cent soya meal. Appendix 4 shows the edible protein production from pigs (single animals) fed from the produce of one hectare to be about;

150 kilogrammes.

The production of concentrate per hectare is based on average US yields of soya beans and maize grain (FAO 1979). Compared to Holmes' (1981) figure for pork production in Table 3, which is about 90 kilogrammes edible protein per hectare, this figure seems rather high. Two factors should be considered, however. Firstly Holmes's data refers to breeding populations and not single animals. Secondly his data refer to the UK and are based on the production of four tonnes of barley based concentrate per hectare, while the figure calculated in Appendix 4 is based on the production of five tonnes of maize based concentrate per hectare.

Appendix 5 shows the calculation of edible protein production (E2) from pigs and fish fed from the produce of one hectare,

using Buck et al's (1976) data to be between;

195 - 199 kilogrammes edible protein per hectare.

It can be seen that the increase in production of edible protein from feeding pig excreta to fish ponds is in the range of :

45 - 49 kilogrammes per hectare.

Table 12 summarises the results of calculations made in sections 3.1 - 3.3.

Table 12

Summary of efficiency calculations (sections 3.1 - 3.3).

Production system	E1 (%)	E2 (kg EP /ha/yr)
Wheat fed carp (Poland)	24 - 29	80 - 90
Pellet fed carp(Poland)		
25% protein	10 - 15	---
40% protein	8 - 11	---
Pigs (Appendix 4)	23	150
Pigs and fish (C. Africa)	69 - 71	---
Pigs and fish (USA)	38 - 43	195 - 199

3.4. Comparison of the efficiencies of conversion of livestock excreta to edible fish protein and to wheat protein.

The "opportunity cost" of using livestock excreta as an input to systems of fish culture, rather than as a fertilizer input to arable crops, can be assessed by comparing the output of edible fish protein per unit livestock excreta input, to the output of wheat protein on the same basis. If the average yield of wheat (at the point on the nitrogen response curve where diminishing marginal returns set in) per kilogramme nitrogen fertilizer applied is taken as a standard, then a manure conversion ratio for wheat can be calculated if the available nitrogen content of the livestock excreta is known. Calculations and typical values are shown in Appendix 6 which also shows similar conversion ratios for fish. Manure conversion ratios for fish have been taken from the literature, in the case of cattle slurry, and calculated from the literature, in the case of pig slurry. The conversion efficiencies of excreta dry matter to wheat protein are about;

0.125 kg. wheat protein per kg. dry matter cattle slurry

and

0.2 kg. wheat protein per kg. dry matter pig slurry.

In comparison, the conversion efficiencies of slurry dry matter to edible fish protein are about;

0.029 kg. edible fish protein per kg. dry matter cattle slurry.

and

0.085 - 0.112 kg. edible fish protein per kg. dry matter pig slurry.

Thus from these calculations it appears that the yield of edible fish protein per unit cattle excreta dry matter is only about;

23 per cent of that of wheat protein

and that the yield of edible fish protein per unit dry matter pig excreta is between;

42.5 per cent and 56 per cent of that of wheat protein

On this basis it seems to be less efficient to use livestock excreta as an input to fish culture than as an input to wheat production.

However, several factors should be considered in the assesment of these calculations. Firstly, edible fish protein is of considerably higher biological value and digestability than wheat protein and is also more palatable to most consumers. Secondly, the manure conversion ratio used in the calculation of the efficiency of conversion of cattle excreta to fish protein, is a mean figure, given by Wohlfarth (1978), for very high fish production levels, whereas the ratios used in the calculation of the efficiency

of conversion of excreta to wheat protein were at the response turning point. It appears from the calculations on Buck et al's data, that there is a diminishing marginal response to excreta inputs in fish culture, just as there is to nitrogen inputs in arable cropping. Thirdly, the available nitrogen content of livestock excreta given by A.D.A.S (1979) assumes timely application of manures in spring or summer. In practical farming some of the available nitrogen may well be lost before it reaches the crop. Furthermore, when livestock excreta is applied to fish ponds some of the nutrient value remains unused, or is recycled within the pond, and accumulates in the pond mud. The Chinese consider that fifty kilogrammes of fish produce enough pond humus to fertilize 6,670 square metres of crop land (FAO 1977).

Chapter 4.

The current status and potential of carp farming in standing water ponds in the UK.

In order to calculate the current and potential protein conversion and protein production efficiencies of various methods of carp farming in the UK, it is first necessary to describe the current status of UK carp farming.

At the time of writing there are only two commercial carp farms in the UK that are regularly producing carp for consumption as food (table carp). There are however several producers of carp and other fish for the restocking of angling waters.

Cotswold Carp Farm at Bourton on the Water, Gloucestershire, which is run by Mr. Tim Farnworth and his son, has been producing table carp regularly since about 1978. More recently (1980) Water Lane Fish Farm, at Bourton Bradstock, Dorset, was set up by Mr. Peer Pratt, and this farm now is producing table carp also. Both these farms produce fish for the restocking as well as the table market. Fairbourne Carp

Farm, at Timsbury, Hampshire, run by Mr. Peter Black, is currently producing carp only for the restocking market but has plans to produce table fish in future years. Humberside Fisheries, at Cleaves Farm, Skern, Drifffield, Yorkshire, run by Mr. Ken Ryder, produces fish only for restocking, and has no plans to go into table carp production, but it is of note because it is the only commercial fish farm in the country producing grass carp and silver carp for introduction to British waters. Newhay Fisheries, at Cliffe, near Selby, Yorkshire, run by Mr. Villi Michaels in conjunction with Warburtons Bakeries, of Bolton, Lancashire, produces carp mostly for the restocking market but is actively trying to encourage the adoption of table carp production by arable and livestock farmers as a new enterprise on their farms. They are offering to supply seed fish and advice and will guarantee a market for any table carp that are produced.

During 1981 1.6 hectares (4 acres) of carp ponds have been constructed on the estate of Mr. Rupert Lawson-Tankred, in Yorkshire, which have been stocked with 10,000 C1 seed fish supplied by Newhay Fisheries (Lawson-Tankred 1981). Mr Simon Fitzherbert-Brockholes of Garstang, Lancashire has about 2.5 hectares (6 acres) of carp ponds, constructed during 1981 which will be producing table carp in the coming year (Fitzherbert-Brockholes 1981). Newhay Fisheries is also involved with several other prospective carp farmers, who intend to start table carp production in 1982.

4.1. The production of carp in the UK.

Table 13 shows the production levels claimed by five of the carp farmers referred to above. This ^{data} ~~is~~ ^{were} collected by the author and ^{are} ~~is~~ based on personal communications in all cases. Mr. Peer Pratt was unable to give a figure for his total annual output. The figures for pond yields refer to ponds that are in full production and all the farmers, other than Michaels, reported that they had ponds that were not used so intensively. The net yields of ponds (ie total yield minus the weight of fish stocked at the beginning of the season) have been calculated on the basis that the weight gain of the fish is seventy-five per cent of the total yield. This figure is derived from the assumption that C2 carp weigh about 250 grammes and grow to C3 fish of about one kilogramme in one season under UK conditions (see section 2.1.1).

From Table 13 it can be seen that over ten tonnes of carp are produced annually from standing water ponds in the UK. It is not possible to determine precisely how much of this production goes to the table market but it is probably about five tonnes a year.

Table 13

Carp production in the UK.

Farm	Annual prod. tonnes	Yields total - net kg/ha/yr	Feed	FCR	Fertilizers
1)	--	1,000 - 750	carp pellets 35% P	1/1	Super phosphate
2)	5	3,700 - 2,775	poultry pellets 15% P	2-2.5/1	Super phosphate + FYM
3)	5-6	1,000 - 750	trout pellets	2.5/1	Ammonium sulphate Super P.+ Turkey manure
4)	20,000 fingerlings	-----	none	---	Horse manure + slurry
5)	1	2,500 - 1,875	Bakery waste	---	Super phosphate + FYM

- 1) Water Lane Fish Farm
 2) Cotswold Carp Farm
 3) Humberside Fisheries
 4) Fairbourne Carp Farm
 5) Newhay Fisheries.

4.2. The protein conversion efficiency and protein production efficiency of carp farming in the UK.

Table 14 shows the protein conversion efficiency E1 of carp produced on three UK farms and the protein production efficiency E2 of carp at Cotswold Carp Farm.

E1 is found to be in the range;

10 - 33 per cent.

This is a considerable range of efficiency but it is of a similar order to that calculated for carp farming in Poland in Chapter 3 (Tables 10 and 11). The FCR reported by Ryder (1981) for Humberside Fisheries seems to be very poor, considering the yield level and feed protein content, when compared to the other two farms. This may be due to several factors, such as variations in management controls; and it should be borne in mind that Humberside Fisheries is operated entirely to produce fish for restocking.

Because poultry pellets are used as feed on Cotswold Carp Farm the production of feed per hectare has been assumed to be four tonnes per year, the same figure as used by Holmes (1977) in his calculations.

Table 14.

Protein conversion and protein production
efficiencies of carp farming in the UK.

Farm	Feed % protein	FCR	E1	E2 kg/ha/yr
1) Water Lane Fish Farm	35	1/1	0.29	--
2) Cotswold Carp Farm	15	2-2.5/1	0.33-0.27	101-116
3) Humberside Fisheries	40	2.5/1	0.1	--

E2 is found to be in the range;

101 - 116 kg. edible protein per hectare per year.

This is somewhat higher than the protein production efficiency of wheat fed common carp in Poland (Table 10). By comparison with the protein production efficiencies shown in Table 3, it can be seen that the efficiency of carp produced under these conditions is between that of pigmeat production and milk and beef production.

It is not possible to calculate E2 for the other two farms. The carp on these farms are fed high protein pellets with a substantial fish meal content derived from marine fishing, rather than pellets that are based on arable products.

Carp at Newhay fisheries are now being raised on bakery wastes which vary considerably in protein content. Experiments to determine optimum feeding rates and methods of feed presentation to the fish, have been carried out over the last year. Preliminary results show that total yields equivalent to over two and a half tonnes per hectare have been achieved, although no data are yet available as to feed conversion rates (Jaffa, 1981).

Because the feed used at Newhay Fisheries is a waste product, it may be assumed that no land is used in its production. Based on this assumption the protein production efficiency E2 of carp production at Newhay Fisheries is ten per cent of

the net yield (edible protein content of fish = ten per cent of fresh weight). Thus E2 is about;

187 kg. edible protein per hectare per year.

By comparison with Table 3 it can be seen that carp production based on the feeding of bakery wastes has a higher efficiency of protein production per unit area than other methods of animal protein production.

It is recognised that bakery wastes could be fed to other farm animals such as pigs. If this was done then the protein production efficiency E2 for pigs would be considerably higher than that shown in table 3. There are however, legislative restrictions on the feeding of food processing wastes to pigs. If bakery wastes (which contain meat products) are fed to pigs they must be sterilised first by boiling. This puts an additional energy cost and thus financial cost on the operation. This is not the case with fish feeding, as there appears to be no risk of disease transmission from waste food to fish. All that is required is the production of a moist pellet from the waste by extrusion a simple food mincer.

Overall it appears that the biological efficiencies of carp farming in the UK are similar to those of intensive carp farming in Poland. These were shown in Chapter 3 to compare favourably with the biological efficiencies of other systems of animal production.

4.3. The yield potential of carp polyculture in manure fed ponds in the UK.

Figure 8 (Chapter 2.2) summarizes the results of Israeli experiments to determine the extent to which animal manures could be used to replace conventional fish feeds. This figure has been redrawn as Figure 9 in order to show the relationship between the yields that may be obtained under different management conditions. Column 2 in Figure 9 represents the yield that may be obtained from what is basically a common carp monoculture fed on commercial pellets (20 per cent protein), but with 7.4 per cent of the fish stock made up of silver carp. In Israel silver carp are added to common carp ponds in order to control excessive algal blooms (Wohlfarth 1978). The yield of common carp alone in column 2 has been assigned a relative yield of unity, and is used as a baseline to which all the columns are related. Columns 5 and 6 have been calculated from Columns 3 and 4 respectively, with the yield of tilapia subtracted from the total yield in each case.

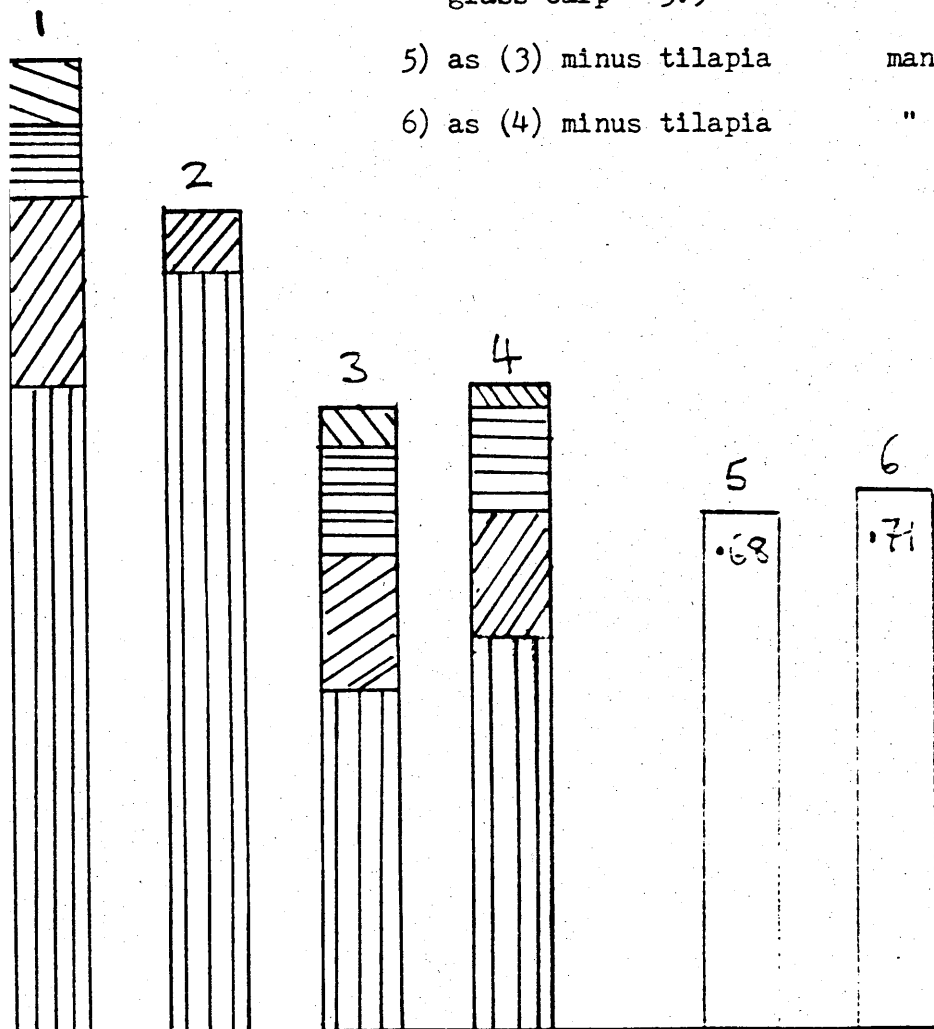
It is assumed for the purposes of this discussion that the relationships between the yields obtained under different management conditions are more or less constant under varying

Figure 9.

Calculated from Wohlfarth (1978)

ds of different methods of stocking and feeding relative
arp monoculture with a commercial pellet feed in Israel.

Fish stock species composition as % biomass	feed
1) common carp 66.6 silver carp 19.9 tilapia 8.1 grass carp 5.4	commercial pellets
2) common carp 92.6 silver carp 7.4	" "
3) common carp 55.3 silver carp 22.2 tilapia 17.1 grass carp 5.4	manure only
4) common carp 61.2 silver carp 18.6 tilapia 16.3 grass carp 3.9	" "
5) as (3) minus tilapia	manure only
6) as (4) minus tilapia	" "



edaphic conditions. One obvious limitation to this assumption is that tilapia will not normally survive under temperate conditions, whereas silver carp, grass carp and common carp will. It is for this reason that Columns 5 and 6 have been added to Figure 9.

Despite the fact that most of the carp farmers in the UK use some animal manure as an input to carp ponds (see Table 13) there have been no experiments to determine the extent to which the use of manures and the manipulation of the species composition of fish ponds, could be used to replace the need for supplementary fish feeds.

Table 15 shows the relative yields of the different species mixes and feeding methods shown in Figure 9. The yield potential for a polyculture of common carp, silver carp and grass carp in manure fed ponds under UK conditions may be estimated by multiplying the reported yields of pellet fed common carp in the UK by the ^arelative yields for carp polyculture in manure fed ponds from Table 15. This is done in Table 16.

It appears from Table 16 that yields in the range :

510 - 1,970 kilogrammes per hectare per year

could be obtained in the UK from a polyculture of common carp, silver carp and grass carp in manure fed ponds without supplementary feeding. If this is the case then the

Table 15.

Relative yields for fish culture under different management conditions.

System	Relative yields
carp monoculture pellet feed	1
carp mono + 7.4% silver carp pellet feed	1.08
carp polyculture + tilapia pellet feed	1.28
carp polyculture + tilapia manure only (1975)	0.82
" " " " (1977)	0.85
carp polyculture less tilapia manure only (1975)	0.68
" " " " (1977)	0.71

Table 16.

The yield potential for manure fed polyculture in the UK.

Range of yields pellet fed carp monoculture (UK) kg/ha/yr	Relative yields for manure fed poyculture (Table 15)	Yield potential for manure fed polyculture (UK) kg/ha/yr
750 -	0.68 -	510 -
2,775	0.71	1,970

efficiency of edible protein production (E2) would be in the range :

51 - 197 kilogrammes edible protein per hectare per year.

These figures are hypothetical, as they are based on an unproven assumption, but if they are compared with the efficiencies of edible protein production of terrestrial farm animals shown in Table 3, it can be seen that at worst the efficiency of edible protein production from carp polyculture in manure fed ponds, without supplementary feeding, would exceed that from both sheep production and suckler beef production and at best exceed that of all conventional methods of animal protein production.

In the discussion of Wohlfarth's (1978) paper, M. Bohl of West Germany stated that his institute (Bayerische Landensanstalt fur Wasserforshung) had found that chicken manure had little effect if the weather was not warm enough, ie below 16 degrees centigrade, and that excess manure led to oxygen depletion problems. Wohlfarth agreed about temperature and suggested that even 16 degrees might be too low. He said that they were afraid to manure in winter in Israel in case of a manure build-up in ponds. The problems associated with the traditional European method of annual manuring, and the development of Woynarovich's "carbon manuring technique" were referred to in section 2.1.2.

It is contended that if the "little but often" principle is

applied to manuring of fish ponds, under northern European conditions, it should be possible to use manure more or less continuously during the growing season to stimulate the growth of natural fish feeds without encountering anoxic conditions due to overloading of the pond. In section 2.1.2 it was pointed out that in countries such as China, where manures are the traditional management tool in fish farming, the application rates are guided by various "rules of thumb" and "craft knowledge" of fish farmers. For manure based systems of fish culture to be successful in the UK it would be necessary for fish farmers to acquire sufficient "craft knowledge" to be able to keep the rate of manuring of a pond in balance with the rate at which manure is converted into fish feed.

Although no experiments have been carried out on continuous manuring of fish ponds in the UK with agriculturally derived manures, there have been at least two sets of experiments on fish growth in sewage treatment lagoons continuously fed with sewage effluent. Noble (1975) achieved a range of net annual yields of common carp grown in tertiary treatment lagoons at Rye Meads, Hertfordshire, without supplementary feeding equivalent to :

381- 856 kilogrammes per hectare per year.

Colclough and Dearsley (1981) achieved a net annual yield of common carp equivalent to:

580 kilogrammes per hectare per year

in tertiary treatment ponds at Stanford Rivers sewage treatment works, Essex, without supplementary feeding.

These results would tend to confirm that organic manuring of fish ponds, stocked with a monoculture of common carp in the UK, can produce yields within the range calculated in Table 16, without supplementary feeding. Whether the yield could be increased to the upper end of the range ie 1,970 kilogrammes per hectare per year, by utilizing polyculture and judicious management of manure application rates has yet to be ascertained.

In Poland where the yield levels attained with common carp monocultures are similar to those reported by UK carp farmers, the introduction of silver and grass carp to common carp ponds increased production by twenty to twenty five per cent (Opuszynski 1968). As mentioned in section 2.1.1 these production increases did not apply to fry rearing ponds.

Ryder (1981) reports that grass carp and silver carp grow very slowly for the first three years, in Yorkshire, reaching a weight of only about 150 grammes after three summers, compared to 1 - 1.5 kilogrammes for common carp of the same age, and that they do not reach a sufficient size in the first year to overwinter. Buckley (1981) reports that in Sussex, grass carp will grow to about 290 grammes in two summers, which is a similar rate of growth to that of common

carp in the UK. There is no experience as yet of growing silver carp beyond 150 grammes in open ponds in the UK. Because of the slow initial growth of grass carp and silver carp in the UK it may be necessary to grow them to fingerling size in artificially warmed water eg power station cooling water, before stocking them in unheated fish ponds. For the same reasons this method of producing phytophagous fish is practised in Poland (Opuszynski, 1971).

Chapter 5.

Experimental Programme

Introduction.

Between 8th August 1979 and 28th April 1980 a series of experiments were carried out by the author with the aim of assessing the potential of human food wastes (canteen plate waste) as a feed for grass carp and common carp in warm water tank culture.

Canteen and other catering wastes represent a major resource that is largely untapped. Roy (1976) states that upto one third of all edible food bought by caterers in the UK is wasted, and that between five and ten per cent of all food consumed in the UK is eaten in catering establishments. Thus the amount of food wasted in catering establishments between about one and three per cent of total UK food consumption.

Common carp have been described as the pigs of the fish world, due to their catholic feeding habits, and grass carp in the wild feed primarily on plant materials. While both species of fish may be grown on a variety of organic wastes

in pond culture, in warm water tank culture and cage culture, eg in power station effluents, they are usually fed with high protein compound feeds. These feeds are formulated according to what is believed to be a nutritional standard necessary for optimum growth and feed utilisation. High protein feeds are expensive to produce both in monetary and support energy terms, as they consist of about fifty per cent marine fish meal. Edwardson (1976) has shown that feeds account for fifty-six per cent of the support energy costs of carp culture in cages in Japan and ninety-three per cent for trout culture in ponds in the UK, and that any system of fish culture that depends on marine fisheries for its feed inputs is always more intensive in energy use than the most intensive sea fishing process, eg deep sea fishing for cod, which is amongst the most energy intensive methods of food production. If high protein foods could be replaced by a waste product, in this case canteen plate waste, then the support energy efficiency of such systems of fish culture could be increased.

Although the protein content of canteen waste was known to be considerably lower than that required for optimum fish growth, it was thought that common carp and grass carp might be grown on it to a marketable size of 250-500 grammes, albeit at a slower rate than on a more nutritionally balanced diet. If this proved to be the case then recirculating water systems of fish culture could be

designed for installation in institutions such as schools and hospitals and could be used to recycle food wastes into edible human food.

5.1. Design, construction and commissioning of the experimental facilities.

Before any experiments could be carried out by the author at the Open University, it was necessary to design and construct experimental facilities for fish culture. This work was carried out in conjunction with Mr. Gary Mantle a research assistant in the Open University Systems Group, between 1st October 1978 and 24th October 1979.

5.1.1. Design and construction.

Six identical warm water recirculating fish culture systems were designed and constructed in the Applied Biosystems Unit Research laboratory. Each recirculating unit was constructed as follows;

a fibre glass (grp) fish tank of 900 litres capacity was connected to an upward flow gravel filter contained in a 230 litre plastic tank. The filter was mounted on a platform above the fish tank. Culture water was pumped from the bottom of the fish tank up through the filter and drained back into the fish tank under gravity.

Fig 10 shows a schematic representation of the system. Each upward flow filter consisted of layers of different sized

Figure 10.

Design of recirculating system.

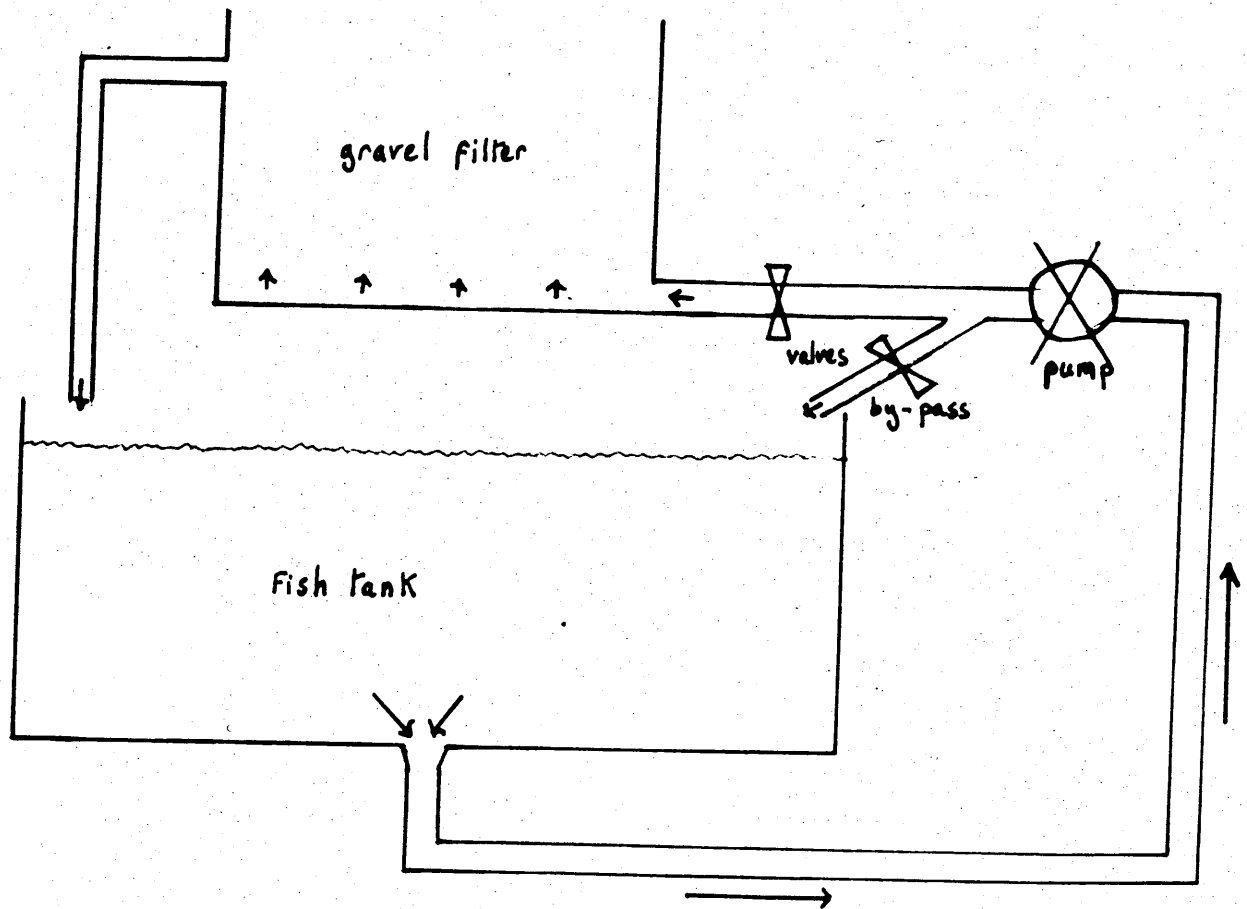
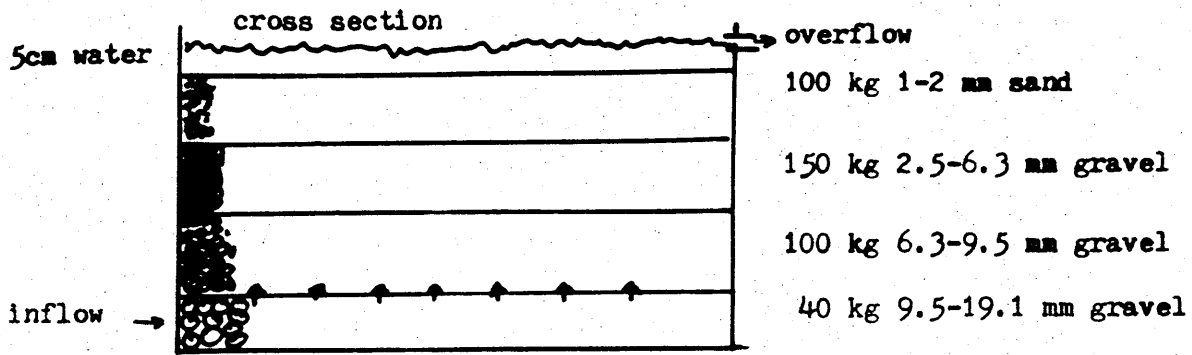
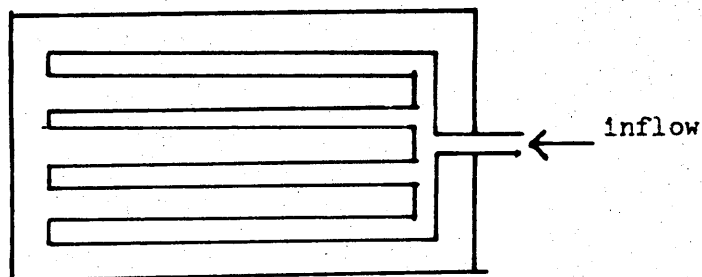


Figure 11.

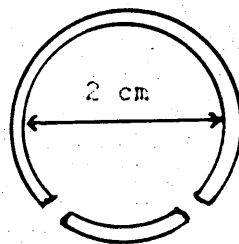
Filter construction.



pipe layout in base of filter bed



cross section of drilled pipe



filter bed base

gravel, over four 2 cm diameter ABS pipes, which had 6 mm holes drilled at intervals along their length. These pipes were laid in the bottom of the filter tanks, and served to distribute the culture water to the filter evenly. Filter construction is shown in Fig 11.

Each fish tank was heated by five 200 watt aquarium heaters controlled by independent thermostats, which allowed the water temperature of each tank to be controlled individually. Each system was fitted with a 0.55 kw electrically driven centrifugal pump connected to the tanks and filters by 2 cm diameter clear plastic reinforced hose. Aeration was supplied to each tank with porous plastic pipe aerators all supplied by a single 0.75 kw ^arotary compressor which served the whole laboratory.

All tanks were filled and subsequently topped up with mains water.

5.1.2. Commissioning.

Before the recirculating systems could be used for fish culture the filters had to be conditioned to ensure that they would treat the excretory products of the fish adequately and prevent a build up of toxic wastes. The first filter to be used was seeded with a suspension of garden soil to establish populations of nitrifying bacteria. This method of conditioning proved to be quick and effective.

Other filters were seeded with a suspension of innoculum taken from the top of the first filter to be established .

The efficacy of all filters was established first by monitoring ammonia levels in the fish tanks, and later by monitoring both ammonia and nitrite levels. During the first phase of commissioning no feed was given to the fish if total ammonia concentrations exceeded 1 mg per litre. During this first phase nitrite levels were not monitored, and high fish mortalities occurred, which were unexplained. After examination of some of the dead fish by Thames Water Authority it was concluded that the mortalities were probably due to nitrite toxicity. Monitoring of nitrite levels was then established on a regular basis and no feed was given if nitrite levels exceeded 0.5 mg per litre. Both ammonia and nitrite were measured by colourimetric methods. Regular monitoring of these water quality parameters brought the level of mortalities under control.

Specific Growth Rates (SGR), defined as;

$$\frac{\log e \text{ final wt} - \log e \text{ initial wt}}{\text{period of growth (days)}} \times 100$$

and Food Conversion Ratios (FCR), defined as;

$$\frac{\text{dry wt of feed fed to fish}}{\text{live wt gain of fish}}$$

are shown in Table 17 for the commissioning period 16th May 1979 to 24th October 1980. In some cases it was not possible

Table 17.

Specific growth rates and food conversion ratios of common carp and grass carp during commissioning phase of experimental facilities. May 16th - October 24th 1979.

Tank no.	fish species	Dates	SGR	FCR
1.	c.c.	16/5 - 21/6	1.94	--
	c.c.	22/6 - 30/7	1.00	--
	g.c.	7/8 - 23/10	1.51	1.96/1
2.	c.c.	16/5 - 22/6	0.16	--
	c.c.	31/7 - 24/9	1.9	1.96/1
	c.c.	24/9 - 15/10	0.65	2.7/1
3.	c.c.	8/8 - 15/10	0.43	--
5.	c.c.	25/5 - 23/6	0.27	--
	g.c.	7/8 - 24/10	1.64	2.56/1
6.	c.c.	16/5 - 23/6	1.64	--
	c.c.	23/6 - 17/8	1.11	--

c.c. = common carp
g.c. = grass carp.

to calculate FCR's because of high fish mortalities. Throughout the commissioning period all fish were fed proprietary carp feed pellets at a rate of approximately three per cent of body weight per day, a nutritional analysis of these pellets is given in Table 18.

By 24th October the experimental facilities were judged to be functioning adequately enough for experimentation in the recirculating systems to begin.

Table 18

Composition of carp pellets.

Protein	35 %
Oil	5 %
Fibre	5.5 %
Ash	10.5 %
Moisture	9.0 %
Carbohydrate	35.0 %

5.2. Aims of the experiments.

To determine:

1. the growth and survival of grass carp and common carp fed on human food wastes.
2. the efficiency of food conversion of fish fed on such a diet.
3. whether there was an interaction between common carp and grass carp reared in the same tank on a diet of waste food.

5.2.1. Feed.

In all cases plate wastes were collected from the Open University canteen. These wastes, which consist mostly of carbohydrate foods such as potatoes, rice and pastry but also included other vegetable material and scraps of meat and fish, were homogenised using a hand operated food mincer. Samples from successive batches of food were oven dried to determine their dry matter content. Fresh food was refrigerated to prevent spoilage, and fed to the fish in the form of a moist paste.

5.3. Experiment 1. Preliminary study. 8th - 30th August
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(Results of all experiments are shown in Table 19.)

Method.

Eighteen common carp weighing a total of 146 grms. and seven grass carp weighing a total of 150.5 grms. were put into two separate aquaria, which were maintained at twenty five degrees centigrade and had under-gravel filters and porous pipe aeration.

The fish were fed for twenty-two days at a rate of approximately six per cent of dry feed to body weight daily.

Observations.

Both species of fish consumed their feed readily although the grass carp seemed keener and quicker than the common carp. The individual size of the grass carp was on average thirteen grammes larger than that of the common carp, and this may have accounted for the different feeding rates.

During the duration of the experiment no problems were encountered with the chemical quality of the water although

Table 19.

Experimental results.

Experiment 1	SGR	FCR
common carp	1.1	4.1/1
grass carp	1.27	3.4/1
Experiment 2		
Stage 1		
common carp (mono)	1.58	2.8/1
grass carp (mono)	1.08	4.6/1
poly. overall	1.44	3.4/1
grass carp (poly)	0.69	--
common carp (poly)	2.03	--
Stage 2.		
common carp (mono)	1.2	5.4/1
grass carp (mono)	0.31	20.7/1
poly. overall	1.42	4.5/1
grass carp (poly)	0.28	--
common carp (poly)	2.05	--
Experiment 3.		
Stage 1.		
common carp (mono)	0.47	6.1/1
poly. overall	0.45	6.3/1
grass carp (poly)	-0.15	--
common carp (poly)	0.84	--
Stage 2.		
common carp	0.12	13.9/1

it did become rather cloudy in appearance after a few days.

Results.

The common carp showed a total weight gain of 38 grms or 26 per cent giving an SGR of 1.1 and an FCR of 4.1/1.

The grass carp showed a total weight gain of 46 grms or 30.6 per cent an SGR of 1.1 and an FCR of 3.4/1.

Conclusions.

Both species seemed to grow well on the waste food diet and no serious problems were encountered. It was decided therefore to conduct a larger experiment over a longer period, to establish whether the growth rates and FCR's could be maintained, and to determine whether polyculture of the two species would have any effect on growth and feed conversion efficiency.

5.4. Food wastage in a school.

Following the success of the preliminary study (5.3) an investigation into food wastage in a school was started. The aim of this investigation was to establish the level of food wastage in a school, so that if further experiments on recycling food wastes through fish were successful, a recirculating fish culture system could be designed for installation in the school, so enabling the recycling of food wastes into edible protein in situ.

The investigation was carried out by pupils at St. Monica's R.C. Combined School, Neath Hill, Milton Keynes, under the direction of a teacher Mrs. Nora Frederickson. A food wastage survey was carried out by four pupils for a three week period during the autumn term of 1979. The results of this survey are shown in Table 20. These show that about ten per cent of all food prepared in the school canteen each week was wasted, and that the daily average weight of waste food was 6.9 kg.

Assuming that the dry matter content of the waste food was similar to that of food wasted in the Open University canteen (35 per cent DM) then 2.4 kg DM of waste food would

Table 20.

Food wastage in a school.

	Wt. of waste range kg	Daily average kg/day	Percentage waste range % /day	Weekly average % /day
week 1	2.2 - 10.2	6.9	4 - 30	13
week 2	3.2 - 11.2	5.8	6 - 17	9
week 3	2.0 - 11.0	7.9	3 - 13	10
average		6.9 kg		10.7%

be available for fish feeding each working day. If the waste food recycling experiments had been successful and FCR's had been maintained at the level shown in the preliminary study (4.1 - 3.4/1) then between 0.58 and 0.7 kg of fish could have been produced from it each day, or between 11.6 and 14 kg per month (20 days). Unfortunately further experiments were not successful and the project was abandoned.

5.5. Experiment 2

Stage 1. 25th October - 11th November 1979

Method.

Three batches of fish of similar size were weighed and placed in three separate recirculating fish culture systems.

Batch one: monoculture of 30 common carp weighing a total of 1175 grms.

Batch two: monoculture of 30 grass carp weighing a total of 1165 grms.

Batch three: polyculture of 15 grass carp weighing a total of 544 grms and 15 common carp weighing a total of 565 grms, giving a total weight for 30 fish of 1109 grms.

Fish of all three batches were fed at approximately five per cent of body weight per day for thirty-two days.

Observations.

Fish in all tanks seemed to feed readily. The water was often cloudy and foamy but no serious water chemistry problems were encountered, during the entire experimental programme.

Ammonia levels varied from < 0.1 - 4.0 mg per litre.

Nitrite levels varied from < 0.1 - 1.0 mg per litre.

Feeding was halted if ammonia exceeded 1 mg per litre or nitrite exceeded 0.15 mg per litre.

Results.

Batch one:

The thirty common carp showed a total weight gain of 776 grms or 66 per cent, an SGR of 1.58 and an FCR of 2.8/1.

Batch two:

The thirty grass carp showed a total weight gain of 480 grms or 41 per cent, an SGR of 1.08 and an FCR of 4.6/1.

Batch three:

The fifteen grass carp and fifteen common carp showed a total weight gain of 650 grms or 59 per cent, an SGR of 1.44 and an FCR of 3.4/1.

The total weight gain of this polyculture batch was made up of 134 grms or 25 per cent (SGR= 0.69) by the grass carp and 516 grms or 91 per cent (SGR= 2.03) by the common carp.

Conclusions.

The best overall growth and FCR was shown by the common carp monoculture with an SGR of 1.58, this was followed by the polyculture batch with an SGR of 1.44 compared with 1.08 for the monoculture of grass carp.

However it was apparent that the common carp were competing

successfully for food with the grass carp in batch three, as the common carp in this batch had an SGR 2.03 compared with 1.58 for the common carp in monoculture, while the grass carp had an SGR of only 0.69 compared with 1.08 for the grass carp in monoculture.

Stage 2. 27th November - 12th December 1979.

Feeding was continued at the same rate for a further two weeks.

Observations.

Fatty scum accumulated on the surface of the water in the tanks, which was composed partly of fatty fish faeces. Much of the canteen waste during this stage of the experiment was made up of fried potatoes. Filter drainage revealed considerable quantities of decaying food particles, which indicated that not all the feed was being consumed.

Results.

Batch one:

The thirty common carp showed a total weight gain of 358 grms or 18 per cent, an SGR of 1.2, and an FCR of 5.4/1.

Batch two:

The thirty grass carp showed a total weight gain of 74 grms or 4 per cent an SGR of 0.31 and an FCR of 20.7/1...

Batch three:

The fifteen grass carp and fifteen common carp showed a total weight gain of 386 grms or 22 per cent, an SGR of 1.42 and an FCR of 4.5/1.

The total weight gain of this polyculture batch was made up of 27 grms or 4 per cent (SGR = 0.28) by the grass carp and 359 grms or 33 per cent (SGR = 2.05) by the common carp.

Conclusions.

In the second stage the polyculture batch showed the best SGR and FCR but this was made up almost entirely of growth by the common carp. The grass carp performed badly in both batches and had very similar SGR's. The FCR's were all poorer than in the first stage of the experiment.

The experiment was terminated at this point. The fish were mixed up and water temperatures in the tanks were reduced to ambient (2-4 degrees C.) for the duration of the winter break. No feed was given during this period.

It was decided to omit the monoculture batch of grass carp in the next experiment and to test a monoculture of common carp against a polyculture of common carp and grass carp. It was also decided to try to increase the feeding rate to eight per cent of body weight per day, as the common carp in polyculture had grown almost twice as much as those in

monoculture indicating that they had consumed more food at the expense of the grass carp.

5.6. Experiment 3.

Stage 1. 10th January - 4th March 1980.

Method.

Two batches of fish from the previous experiment were weighed and placed in two separate tanks as before. (The temperature of the fish had been brought back up to 25 degrees C. over several days.)

Batch one: monoculture of 30 common carp weighing a total of 2551 grms.

Batch two: polyculture of 15 common carp weighing a total of 1299 grms and 15 grass carp weighing a total of 1104 grms the total weight of the 30 fish was 2403 grms.

The fish were fed at approximately eight per cent of bodyweight (split into two portions) for fifty-three days.

Observations.

On most days the first (morning) portion of feed was not consumed by the evening and no second portion was given. On several occasions ammonia levels exceeded 1 ppm and feeding

was stopped until the level fell below 1 ppm.

In the sixth week of the experiment the grass carp started to die and on the 30th March only two grass carp were still alive, both ammonia and nitrite levels were below laboratory safety limits during this period. Dissection of the dead grass carp revealed that the liver was abnormally pale and was disintegrating. This was thought to be fatty degeneration of the liver as described by Amlacher (1970).

Results.

Batch one:

The thirty common carp in monoculture showed a total weight gain of 722 grms or 28 per cent, an SGR of 0.47 and an FCR of 6.1/1.

Batch two:

The fifteen grass carp and common carp together showed a total weight gain of 643 grms or 27 per cent, an SGR of 0.45 and an FCR of 6.3/1, but the fifteen grass carp (including the weights of the dead fish) had lost 82 grms or 7 per cent while the fifteen common carp had gained 725 grms or 56 per cent and had an SGR of 0.84.

Conclusions.

Both FCR and growth rates had fallen below the levels in Experiment 2. stages 1 and 2, but the fifteen common carp in

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polyculture showed almost double the growth rate of those in monoculture showing that they had again eaten extra feed at the expense of the grass carp.

The death of the grass carp suggested that the diet was too fatty for them and also probably deficient in protein and other nutrients. The experiment was continued using only common carp.

Stage 2. 4th March - 28th April 1980.

Method.

Forty three common carp weighing a total of 5123 grms were placed in a tank as before and fed to appetite for 55 days.

Observations.

Generally the fish fed more slowly and consumed less than previously. Problems were encountered again with the accumulation of fatty faeces and uneaten feed which tended to block the filter screen on the tank outlet.

Results.

At the final weighing the fish had gained 355 grms or 7 per cent with an SGR 0.12 and an FCR of 13.9/1.

Conclusions.

Growth rate and FCR had fallen again and this was consistent

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with previous results showing a progressively worsening performance of common carp on the waste food diet.

On dissection one of the carp was found to have signs of fatty degeneration of the liver and was discoloured yellow inside.

The experiment was abandoned. It was deduced that waste food alone would not sustain growth over a long enough period to raise common carp to a marketable size.

5.7. Overall conclusions on the three experiments.

With hindsight it was probably naive to expect any of the fish to survive long on a diet which was made up almost entirely of carbohydrate and fat. The protein sparing effect of carbohydrate feeds in standing water ponds was described in section 2.1.3., but in tank culture, unlike in pond culture, there are no "natural" sources of protein produced.

The experiments did show however, that both species of fish would consume canteen waste and that they could use it to some extent for growth. The overall conclusion was that such a feed would be excellent for use as a supplementary feed for fish culture in standing water ponds.

Since conducting these experiments this practice has been observed in Thailand (Lawson, 1981). References to it also occur in the Chinese aquaculture literature (Hoffmann, 1934).

Additionally, Warburtons Bakery conducted experiments using bakery waste as a feed for common carp in tank culture with similar conclusions (Colwell, 1981). These conclusions led Warburtons to experiment with bakery waste in ponds at Newhay Fisheries. The results from the 1981 experiments at

Newhay show that food wastes are an extremely effective supplementary feed (Jaffa, 1981).

Chapter 6.

Resource requirements, economics and marketing for fish culture in standing water ponds in the UK.

6.1. Resource requirements.

The following basic inputs are required for fish culture in standing water ponds; Land, Ponds, Water, Equipment and Machinery, Fuels, Feeds, Fertilizers, Seed Fish, Labour and Capital.

6.1.1. Land.

In general land of poor quality for other agricultural purposes, may be excavated to form earth ponds for fish culture. Certain limitations apply however, in that there must be an available water supply and the sub-soil must be of a type that will hold water. Very sandy or gravelly soils may thus be unsuitable for pond construction because of their porosity, as may boulder clays, which are subject to cracking. Rocky soils may present mechanical problems for pond construction.

6.1.2. Ponds.

Recommendations for fish culture in standing water ponds in Europe are that ponds should be 1-1.5 metres in depth and should be fully drainable. Ponds less than one metre in depth are subject to too great temperature fluctuations, and those of over one and a half metres deep will be slow to warm up in the growing season. Deeper ponds could be used for instance to double as irrigation reservoirs on arable farms, but this may involve some sacrifice of fish yields. Ponds should be fully drainable so as to enable complete harvesting of fish and to allow treatment of the pond bottom for fertilization and pest control purposes.

6.1.3. Water.

Water may be supplied from rivers, streams, lakes, ground water or run-off as long as availability is sufficient to ensure pond filling at the beginning of the season (March/April) and to top-up evaporation and seepage losses during the summer months. In many cases land relief is such that gravity may be used to fill and empty the ponds, in other cases pumps will be required. Water should be free of pollutants that are toxic to fish.

6.1.4. Equipment and machinery.

Ponds must be equipped with screened sluices, to prevent wild fish entering with top-up water, and with a monk or similar construction to enable pond drainage without the fish

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escaping. Pumps are required on farms that do not have a gravity water supply or drainage system.

Tractors and associated field equipment may be required for pond preparation, fertilizing and for on farm transport operations.

6.1.5. Fuels - direct energy supplies.

Petroleum spirit or electricity are necessary for running pumps, tractors and other machinery when these are used on fish farms.

6.1.6. Feeds and fertilizers.

The range of feeds and fertilizers that may be used for fish culture has been dealt with extensively in previous sections.

6.1.7. Seed fish.

Seed fish for stocking ponds may be produced on the farm or bought in from specialist producers. Both methods are in use by UK carp farmers at present. On farm seed fish production requires additional investment in breeding ponds or equipment for induced spawning and artificial fry rearing. Farnworth (1981), Black (1981) and Pratt (1981) report that natural spawning is unreliable in the UK because of unpredictable weather conditions. Farnworth has recently changed to induced spawning, and fry rearing in running spring water. Newhay (1981) and Ryder (1981) also use

induced spawning and rear their fry in warm water recirculating systems. These methods enable a reliable year round supply of seed fish.

6.1.8. Labour.

Very little data on labour requirements for fish culture in standing water ponds is available. However Edwardson (1976) quotes a figure of thirteen man days per tonne of carp produced as being a typical labour input to intensive carp farming in Germany.

6.1.9. Capital.

The main capital requirement for fish culture in standing water ponds, is fixed capital for pond construction. Edwardson (1976) states that the estimated lifetime of an earth pond is at least fifty years, thus amortised capital requirements may be very low.

Working capital is required for annual purchases of fuels, feeds, fertilizers and seed fish. (See 6.2).

6.2. The economics of carp farming.

The following calculations are based on the assumption that a farmer investing in a carp farming enterprise, has land on his farm that is suitable for pond construction and unsuitable for other agricultural purposes (with the possible exception of rough grazing). Examples of this type of land are; flood meadows and other low lying areas prone to water logging.

6.2.1. Fixed capital costs.

The main capital cost in setting up a carp enterprise is the cost of pond construction. Contractors' rates for pond construction are estimated to vary between;

£2,500 and £6,250 per hectare of pond

including installation and construction of ancillary equipment such as sluices and monks. The actual costs incurred will depend on the lie of the land and access for earth moving machinery at individual sites (Wrights Construction, 1981) and (Colwell, 1982). These costs could be substantially reduced if a farmer could carry out the pond construction himself or if existing ponds or irrigation reservoirs were to be converted for carp farming.

6.2.2. Annual budget for a hypothetical four hectare carp enterprise.

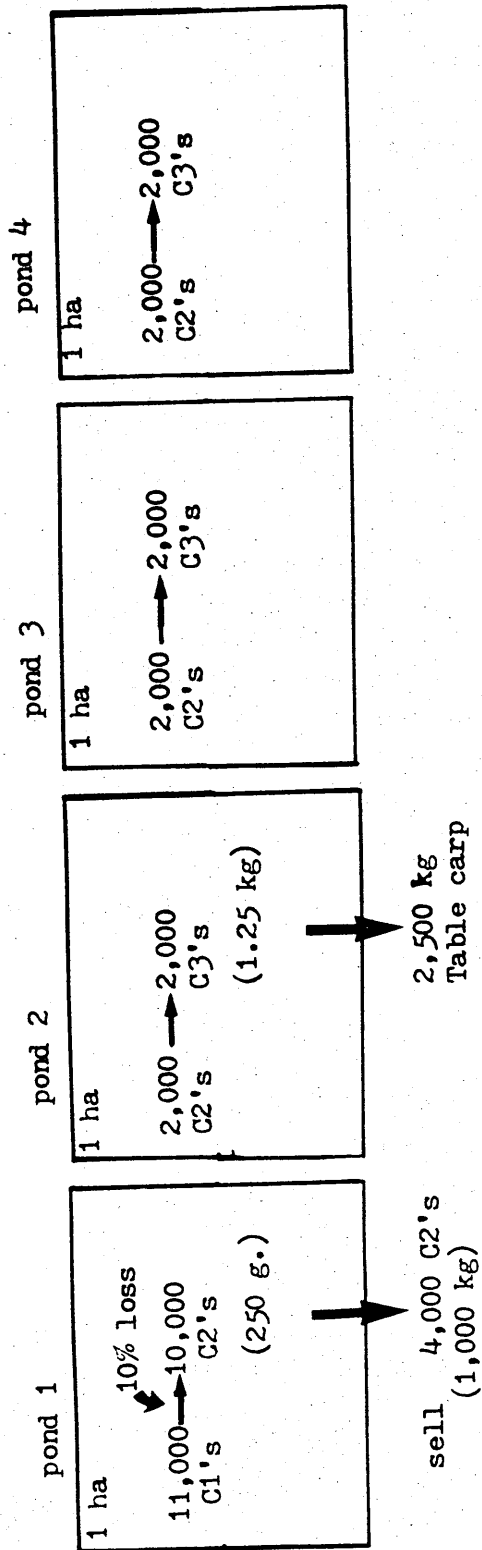
Figure 12 outlines the annual production cycle of a hypothetical four hectare carp enterprise with four ponds of one hectare each. Each pond is assumed to have an annual production of two and a half tonnes of fish per hectare, based on the European method of manuring and supplementary feeding with cereals.

Pond 1 is stocked with 11,000 C1. fish at the beginning of each year and allowing for ten per cent mortality this pond produces 10,000 C2's (250-300 grms.) at the end of the season. Of these 6,000 are retained each year and stocked in ponds 2-4. Each of these ponds produces 2,000 C3's (1-1.5 kg.) at the end of each season (mortality of C2-C3's is usually negligible)(Michaels, 1981). The 4,000 C2's not required for restocking ponds 2-4. are sold as table fish, for smoking or for restocking, along with the 6,000 C3's from ponds 2-4.

Table 21 shows an annual financial budget and gross margin analysis for this hypothetical carp enterprise, based on 1981/82 prices. The production target of the enterprise is two and a half tonnes per hectare, but the financial analysis is carried out for three production levels that may be achieved ie two and a half, two and one and a half tonnes per hectare. This is to give an indication of what might

Figure 12.

Annual production cycle on a four hectare
carp farming enterprise. (producing 2.5t/ha/yr)



Annual revenue	
Pond 1	1,000 kg C2's @ £1.75/kg
Ponds 2-4	7,500 kg C3's @ £2.20/kg
Total	<u>£18,250</u>

Table 21.

Gross margin analysis and annual budget for a four hectare carp enterprise.

(Calculations based on a production target of 2.5 tonnes per ha. but actual production levels of 2.5t, 2t and 1t per hectare.)

Variable costs :

Fertilizers (based on Newhay recommendations)	
lime 750 kg. at £0.11/kg.	=£ 82.50
manure 100 tonnes at £1/tonne	=£ 100
superphosphate 2 tonnes at £70/tonne	=£ 140

Feed (assuming FCR = 3.5/1.)	
feeding grains 35 tonnes at £100/tonne	=£ 3850

Seed fish	
11,000 C1's at £180/1,000	=£ 1980

Total variable costs	=£ 6153
----------------------	---------

Annual revenue	at 2.5 t/ha	at 2t/ha	at 1.5t/ha
C2's at £1.75/kg.	1.0t =£ 1750	0.8t =£ 1400	0.6t =£ 1050
C3's at £2.20/kg.	7.5t =£16500	6.0t =£13200	4.5t =£ 9900
Total revenue	=£18250	=£14600	=£10950
Gross margin for four hectare farm	=£12097	=£ 8447	=£ 4797
Gross margin per hectare	=£ 3024	=£ 2111	=£ 1199

Average annual Capital and Interest repayments amortised over ten years at 10% interest (Nix 1982) for construction of ponds :

at £2500/ha.	=£ 408
at £6250/ha.	=£ 1019

Annual profit per hectare before labour and other fixed costs:-			
	=£ 2005	=£ 1092	=£ 180
	-	-	-
	£ 2616	£ 1703	£ 791

happen in good, average and bad years.

From Table 21 it can be seen that this carp enterprise would have a gross margin of between; £1,119 and £3,024 per hectare.

Deducting average capital and interest repayments at two levels of pond construction costs (each amortised over ten years at ten per cent interest) the annual profit per hectare before labour and other fixed costs, lies between; £180 and £2,616.

This is a considerable range, the lower figure representing the results of a bad year with high pond construction costs and the higher figure a good year on an enterprise with low pond construction costs.

In an average year annual profit per hectare, before labour and other fixed costs is likely to be between; £1,092 and £1703 (production level = 2t/ha), depending on pond construction costs.

In certain cases water-logged land that is suitable for pond construction may also be suitable for drainage and subsequently used for a variety of other agricultural enterprises. The average contractors' price for drainage in the UK is;

£625 per hectare (Farmers Weekly, 1982).

Farm drainage may be grant aided at the following rates;

37.5 % under the Agriculture and Horticulture Grant Scheme, and
50 % under the Agriculture and Horticulture Development Scheme (Nix, 1982).

Table 22 shows average gross margins for various common farm enterprises, annual capital and interest repayments for drainage costs after two levels of grant aid (amortised over ten years at ten per cent interest) and the resulting profit per hectare before labour and other fixed costs.

Comparing the results of in Table 21 with those in Table 22 shows that in an average year carp production is likely to be more profitable than the more common farm enterprises, when compared on similar basis.

For a true comparison of profitability the remaining fixed costs must be considered. Since there are no UK data available for carp production as a farm enterprise it is very difficult to make meaningful assumptions as to how fixed costs are likely to change on a farm as a result of introducing carp production. On a mixed farm it is likely that existing machinery will be available for use in a new carp enterprise, thus increases in machinery costs are likely to be only marginal. Increases in labour costs however will probably be significant because of the "lumpy" nature of labour as a resource which means that a new carp enterprise

Table 22.

Gross margins, drainage costs and profit margins of common farm enterprises

Enterprise	Average GM/ha	Annual repayments for drainage (at 2 grant levels)	Profit before labour & other fixed costs
Winter wheat (feed)	£508	£64 - £51	£444 - £457
Winter barley (feed)	£405	"	£341 - £354
(malting)	£454	"	£390 - £403
Maincrop potatoes	£1005	"	£941 - £954
Dairy (per forage ha)	£823	"	£759 - £772
24 month beef (autumn calves)	£274	"	£210 - £223

Gross margin figures from Nix (1982).

might well involve taking on an additional man. These factors would have to be taken into account by any farmer considering carp production in relation to his own farm.

In conclusion it may be said that, on paper, carp production is certainly competitive with other farm enterprises in financial terms, on farms that have suitable resources available.

6.3. The market for table carp in the UK.

Current estimates of the existing market for table carp in the UK vary from about 700-1,000 tonnes of fish per year, which is equivalent to one to two million pounds per year. This market is almost exclusively an ethnic market, made up of Eastern European, Pakistani, Indian and Chinese immigrants for whom carp is a traditional food (Walsingham, 1980; Colwell, 1981). No comprehensive market survey has yet been carried out, but Colwell (1982) states that the estimates above are based on discussions with informed contacts in the fish trade.

A market survey has been commissioned recently by the Central Council for Agricultural and Horticultural Cooperation on behalf of a working party of carp farmers who are investigating the potential for setting up a carp marketing cooperative. The market survey will investigate the consumer market for carp as;

- a) live carp
- b) frozen carp

by researching,
market outlets eg:

-ethnic minorities (key area)

-foreign clubs

-delicatessen shops

-Chinese restaurants

-Lewis's and Harrods

-major fish markets

seasonality of demand:

a) traditional (ie Christmas period for Eastern Europeans)

b) all year round

and product image:

-where the product is sold currently, what is its image?

(Parker J. 1982).

The existing market is supplied almost entirely by imports from Eastern Europe (Comecon countries) and Israel, at present. Those few existing English carp farmers all report that orders for fish far outstrip their production. If the market is in the region of one thousand tonnes of carp per year then approximately four hundred hectares of carp ponds would be required to meet existing demand from home supplies.

The aims of the Carp Marketing Group working party are to form a marketing cooperative:

a) to market carp and associated fish for human consumption and/or angling outlets and

b) to assist members in

- food buying
- equipment buying
- equipment sharing or inter member hiring eg catching nets.

The cooperative is considered to have a potential membership of twenty, although due to the keen interest shown at meetings and seminars on carp farming organised by Newhay, this figure is expected to rise quickly (Parker ibid.).

Chapter 7.

Conclusions and recommendations for further study.

The hypothesis investigated in this study is that the introduction of fish culture as an integral part of the UK farming system would result in an increase in the efficiency of utilization of certain classes of agricultural land and other biological resources, that are underutilized or wasted at present.

It has been argued that, in a situation of current or impending food scarcity, animals should be used as;

- a) converters of resources which are unavailable or unsuitable for direct human consumption, and
- b) collectors and concentrators of resources from land that cannot be cropped conveniently by other means.

Furthermore it has been argued that in choosing between animals, prominence should be given to those animals that are best suited to meeting roles (a) and (b) in terms of efficiency of protein conversion, efficiency of protein production per unit area, and efficiency of protein

production per unit support energy input.

7.1. Conclusions.

This study has shown that the raising of carp and other cyprinids in standing water ponds is currently practised to a limited extent in the UK, but was once more widely practised. In the past, such systems of fish culture were integrated with other agricultural systems in that they made direct use of agricultural outputs and by-products eg cereal brans, other food processing residues, and animal excreta.

It has been shown that fish culture systems are comparable with other systems of animal production in terms of the relevant efficiency criteria outlined above, and that they are subject to similar variations in intensity, ie from systems that rely on natural productivity to those that are dependant on an input of nutritionally balanced feed.

The culture of trout and other fish by intensive methods which rely on marine fish meal for a substantial proportion of feed inputs, has a similar efficiency of protein conversion to other intensive methods of animal production, but a much lower efficiency of support energy use. In contrast carp culture in standing water ponds based on cereals and inorganic fertilizer inputs has an energetic efficiency in the same order as conventional methods of

animal production. It is contended that the use of organic wastes - manures and food processing residues - to replace cereals and inorganic fertilizers in carp culture, would further increase the efficiency of support energy use.

Systems of fish culture in standing water ponds can make use of land that is of poor quality for other agricultural uses and can convert materials, that are unsuitable for direct human consumption, into high quality edible protein. The areas of land occupied by pond banks (bunds) need not be wasted but may be used for grazing cattle or sheep or to grow feeds for phytophagous fish such as grass carp that are stocked in the ponds.

When cereals are used as a supplementary feed in carp culture, the efficiency of protein conversion, can exceed that of poultry production which is the most efficient converter of protein of all conventional animal production systems. Efficiency of protein production per unit area (including ghost hectares for feed production) is found to be of the same order as that of dairy beef and pig production systems, which have mid-range efficiencies compared with other conventional animal production systems.

Both efficiency of protein conversion and production per unit area of conventional systems of animal production, can be increased by integration with fish culture, so that

animal excreta is used as a feed input to the fish. The efficiency of conversion of excreta to animal protein by these methods compares favourably with its use as a fertilizer for arable cropping, when the biological value and palatability of the protein produced are taken into account.

When waste food is used as a supplementary feed in carp culture the efficiency of protein production per unit area can exceed that of other systems of animal production.

When animal excreta is used as the sole feed input to carp culture, the efficiency of protein production per unit area is at least as good as that of ruminant grazing systems, which have been shown to be the most directly comparable system of animal protein production. Evidence suggests that manure based systems of fish culture in the UK, using a polyculture of common carp and phytophagous cyprinids, have a potential protein production efficiency that exceeds that of all conventional methods of animal protein production.

All the resources necessary for fish culture in standing water ponds are available within the UK including seed fish which can be supplied by existing specialist producers.

Carp farming by conventional European methods would appear to be viable in economic terms, when current UK prices are applied in a financial analysis. The existing market for

carp in the UK is approximately one hundred times larger than existing domestic production and no marketing problems should be encountered in the foreseeable future. Although no market information is available with regard to other cyprinids eg grass carp and silver carp, these are now accepted table fish in all countries in which carp culture is common practice.

Overall it may be concluded that from the point of view of both biological and economic efficiency the culture of fish in standing water ponds compares very favourably with existing methods of animal production in the UK. Furthermore such systems of fish culture can make use of areas of land and other agricultural resources that are underutilized at present for the production of a high quality protein food for human consumption.

7.2. Recommendations for further study.

In view of the calculated potential protein production efficiency of manure based polyculture in standing water ponds, it is suggested that such systems of fish culture should be investigated by experiments on UK farms.

Experiments should be set up with the following aims:

a) to determine stocking rates and species mixes for optimum production.

b) to determine optimum organic loading rates for fish ponds.

c) to determine which types of organic wastes are suitable inputs for fish culture under UK conditions and which types are not.

and

d) from the results of (a) (b) and (c) to draw up guidelines for farmers on the design and running of manure based systems of fish culture on their farms, so that optimum use of available organic wastes and by-products is made.

Appendix 1.Common and latin names of cyprinids.

Common name	Latin name
Common carp / Mirror carp	<u>Cyprinus carpio</u>
Grass carp	<u>Ctenopharyngodon idella</u>
Silver carp	<u>Hypophthalmichthys</u> <u>molitrix</u>
Bighead carp	<u>Aristichthys nobilis</u>
Mud carp	<u>Cirrhinus molitorella.</u>

Appendix 2.

Calculation of the protein conversion efficiency of integrated pig and fish culture in Central Africa.

Data from Nugent 1978.

Fish used : Tilapia Nilotica and Clarius Lazera polyculture.

Fish yields :-

- a) Excreta from 50 pigs housed over 1 ha. of pond gave :- 7,700 kg./yr.
 b) Excreta from 30 pigs housed over 1 ha. of pond gave :- 4,800 kg./yr.

Two cycles of pigs fattened per year over each pond, each cycle fattened from weaners, one and a half to three months old, upto 60-80 kg.L.W.

Therefore assume 50 kg. L.W. gain per pig in six months.

Equivalent to 100 kg. L.W. gain per pig per year.

Data assumptions not given by Nugent (from Table 8.)

- 3) Edible protein content of fish as % L.W. = 10.0%
 6) Edible protein content of pigs as % L.W. = 7.5%
 7) Protein conversion efficiency of pigs = 23.0%
 8) Crude protein consumed per kg. L.W. gain = 0.33 kg./kg.

$E1 = \frac{\text{Edible pig protein} + \text{Edible fish protein}}{\text{Crude protein consumed by pigs.}}$

a) E1 at 50 pigs per ha. of pond :-

$$E1 = \frac{(50 \times 100 \times 0.075) + (7,700 \times 0.1)}{(50 \times 100 \times 0.33)}$$

$$E1 = 0.69$$

b) E1 at 30 pigs per ha. of pond :-

$$E1 = \frac{(30 \times 100 \times 0.075) + (4,800 \times 0.1)}{(30 \times 100 \times 0.33)}$$

$$E1 = 0.71$$

Range of protein conversion efficiency for pigs and fish :-

69 - 71 %.

Appendix 3.

Calculation of the protein conversion efficiency of integrated pig and fish culture in Illinois U.S.A.

Data from Buck et al. 1976. based on one season of fish growth (170 days).

Fish used :-	Species	% of initial biomass stocked
	silver carp	35
	common carp	45
	grass carp	3
	bighead carp	5.5
	hybrid buffalo fish	10
	channel catfish	1
	large mouth bass	0.5

Fish yields :-

- a) Excreta from 39 pigs to each ha. of pond gave : 2,971 kg. 76
 b) Excreta from 66 pigs to each ha. of pond gave : 3,834 kg. 38

Two cycles of pigs fattened in 170 day season.

Live weight gain of pigs in 1st. cycle = 56 kg. per pig
 " " " " " 2nd. cycle = 57 kg. per pig
 equivalent to a total L.W. gain over season = 113 kg. per pig

Data assumptions not given by Buck et al. as in Appendix 2.

a) E1 at 39 pigs per ha. of pond :-

$$E1 = \frac{(39 \times 113 \times 0.075) + (2,971 \times 0.1)}{(39 \times 113 \times 0.33)}$$

$$E1 = 0.43$$

b) E1 at 66 pigs per ha. of pond :-

$$E1 = \frac{(66 \times 113 \times 0.075) + (3,834 \times 0.1)}{(66 \times 113 \times 0.33)}$$

$$E1 = 0.38$$

Range of protein conversion efficiency for pigs and fish :-

38 - 43 %

Appendix 4.

Calculation of the production of edible protein from pigs fed from the produce of one hectare in the USA.

Data:- composition of pig feeds :- approx. 90% maize meal.
(Buck et al 1976) 10% soya meal.

Average yield of maize grain USA : 6 tonnes per ha.
Average yield of soya beans USA : 2 tonnes per ha. (FAO 1979).

From above : production of pig feed per ha. :- 5 tonnes.

Concentrate fed per kg. pig L.W. gain :- 2.51 kg. (Table 8 (10)).

Therefore :- Live weight gain of pigs fed from produce of one ha.
= 1992 kg.

Edible protein as % live weight pigs :- 7.5% (Table 8 (6)).

Therefore :- Edible protein from pigs (single animals) fed from the produce of one hectare

= 149.4 kg.

Appendix 5.

Calculation of the production of edible protein per hectare from integrated pig and fish culture in Illinois USA.

Data as in Appendices 3 and 4.

Calculation :-

$$E2 = \frac{\text{Edible pig protein} + \text{Edible fish protein}}{\text{Area to produce pig feed} + \text{Area to grow fish}}$$

a) E2 at 39 pigs per ha. of pond

$$E2 = \frac{(39 \times 113 \times 0.075) + (2971 \times 0.1)}{(39 \times 113 \times 2.51 / 5,000) + 1.}$$

$$E2 = 195.4 \text{ kg. per ha.}$$

b) E2 at 66 pigs per ha. of pond

$$E2 = \frac{(66 \times 113 \times 0.075) + (3834 \times 0.1)}{(66 \times 113 \times 2.51 / 5,000) + 1.}$$

$$E2 = 198.7 \text{ kg. per ha.}$$

Edible protein production per hectare of land used to produce feed for pigs and fish :-

$$= 195 - 199 \text{ kg. edible protein per hectare.}$$

Appendix 6.

Calculation of the efficiencies of conversion of livestock excreta to edible fish protein and to wheat protein.

Data used :-

Mean manure conversion ratio

(Dry matter cattle slurry : Fresh fish) : 3.5 : 1.
(Wohlfarth 1978)

Fertilizer Nitrogen conversion ratio

(Kilogrammes N : kg. wheat grain) : 0.02 : 1.
average for UK at N response turning point
(Lewis and Tatchell 1979)

Data from Table 8.

1) Crude protein content of wheat	= 10%
3) Edible protein content of fish	= 10%
12) Available N as % D.M. cattle slurry	= 2.5%
13) Output of excreta D.M. from 50-80 kg. pig	= 0.4 kg./day.
14) Available N as % D.M. pig excreta	= 4%

Calculation:-

1 kg N produces 50 kg wheat

therefore :

1 kg cattle slurry D.M. produces : 50 x 0.025 kg wheat
= 1.25 kg.wheat
equivalent to : 0.125 kg.wheat protein

1 kg pig slurry D.M. produces : 50 x 0.04 kg.wheat
= 2.0 kg wheat
equivalent to : 0.2 kg.wheat protein

Using Wohlfarth's Manure conversion ratio

1 kg D.M. cattle slurry produces : 0.29 kg.fish
equivalent to : 0.029 kg.edible protein

From Buck et al's data :-

Excreta from 39 pigs over 170 days gave : 2971 kg.fish
" " " 66 " " " " : 3834 kg.fish

assuming excreta output per pig per day = 0.4 kg. D.M. (13)

then output per pig over 170 days = 68 kg. D.M.

therefore:

1 kg. D.M. pig slurry produces between :

$$\frac{3834}{68 \times 66} \quad \text{and} \quad \frac{2971}{68 \times 39} = 0.85-1.12 \text{ kg.fish}$$

therefore:

1 kg D.M. pig slurry produces between

: 0.085 and 0.112 kg edible protein.

References.

ADAS. (1979). Fertilizer Recommendations. HMSO.

Allen, G.H. and Hepher, B. (1976). Recycling of Wastes Through Aquaculture, and Constraints to Wider Application. In: Pillay, T.V.R. and Dill, W.A. (Eds.). (1979).

Amlacher, E. (1970). The Textbook of Fish Diseases. T.F.H. Publ.

Bardach, J.E., Ryther, J.H. and Mc.Larney, W.O. (1972). Aquaculture. Wiley-Interscience.

Buck, D.H., Baur, B.J. and Rose, C.R. (1976). Experiments in Recycling Swine Manure in Fish Ponds. In: Pillay et.al. (Eds.). (1979).

Buckley, B.R. (1981). Practical Problems with the Use of Grass Carp for Weed Control. Proc. Conf. Aquatic Weeds and Their Control.

Colcough, S.R. and Dearsley, A.F. (1981). A Progress Report on Fish Rearing at Stanford Rivers Sewage Treatment Works. Thames Water Authority, Lea Division.- Internal Report, Ref.: SL.3/001K/A March 1981.

Colwell, K. (1981) and (1982). Pers. Comm. Warburtons Bakery / Newhay Fisheries. Selby, Yorks.

De Bont, A.F. (1948). Fish Farming in the Belgian Congo. Nature, 162, pp998.

Delmendo, M.N. (1980). A Review of Integrated Aquaculture - Agriculture Farming Systems and Constraints to Development. FAO Reg. Prog. Bangkok.

Drummond, J.C. and Wilbraham, A. (1959). The Englishman's Food - A History of Five Centuries of English Diet. Readers Union / Johnathon Cape.

Duckham, A.N., Jones, J.G.W. and Roberts, E.H. (1976). (Eds.). Food Production and Consumption. The Efficiency of Human Food Chains and Nutrient Cycles. North-Holland, Amsterdam.

Duckham, et.al.. (1976). The Function and Efficiency of Human Food Chains. In: Duckham, et.al. (1976).

Edwards, P.E. (1980). A Review of Recycling Organic Wastes into Fish, With Emphasis on the Tropics. Aquaculture, 21.

Edwards, R.W. and Densem, J.W. (1980). Fish From Sewage. Applied Biology, 5.

Edwardson, W. (1976). Fish Farming. SARU Report No.6. Energy Analysis Unit. University of Strathclyde.

FAO. (1977). Freshwater Fisheries and Aquaculture in China. Fisheries Technical Paper No. 168.

FAO. (1977)ii. China: Recycling of Organic Wastes in Agriculture. FAO Soils Bull. 40.

FAO. (1979). Production Yearbook. Vol. 33.

Farmers Weekly. (1982). Drainage Extra. 24/4/82.

Farnworth, T. (1981). Pers. Comm. Carp Farmer, Cotswold Carp Farm, Bourton on the Water, Gloucs.

Fitzherbert-Brockholes, S. (1981). Pers. Comm. Carp Farmer. Garstang, Lancs.

Hepher, B. (1972). Supplementary Feeding in Fish Culture. Proc. 9th. Int. Congr. Nutr. Mexico 1972. 3, pp183-198. Karger, Basel. 1975.

Hickling, C.F. (1948). Fish Farming in the Middle and Far East. Nature, 161, pp748.

Hoffmann, W.E. (1934). Preliminary Notes on the Freshwater Fish Industry of South China Especially Kwangtung Province. Lingnan University. Sci. Bull. No.5. Canton, China.

Holmes, W. (1977). Choosing Between Animals. Phil. Trans. R. Soc. London B. 281, pp121-137.

Holmes, W. (1981). Cattle. Biologist, 28, (5), pp273-279.

Homb, T. and Joshi, D.C. (1973). The Biological Efficiency of Protein Production by Stall Fed Ruminants. In: Jones, J.G.W. (Ed.). (1973).

Jaffa, M. (1981). Pers. Comm. Dept. Applied Bio. University of Aston.

Jones, J.G.W. (1973). (Ed.) Biological Efficiency of Protein Production. Cambridge University Press.

Kreuzer, R. (1974). Fish and Its Place in Culture. In: Fishery Products. (Kreuzer, R. (Ed.)). FAO/Fishing News Books Ltd..

Large, R.V. (1976). The Food Production Efficiency of Undomesticated Species of Animals. In: Duckham et.al.(Eds.) (1976).

Lawson, S. (1981). Inland Fish Culture in Thailand. Applied Biosystems Unit, Research Monograph. Open University.

Lawson-Tankered. (1981). Pers. Comm. Carp Farmer, Yorkshire.

Leach, G. (1976). Industrial Energy in Human Food Chains. In: Duckham et.al. (Eds.). (1976).

Leach, G. (1976). Energy and Food Production. IPC Business Press Ltd.

Lewis, D.A. and Tatchell, J.A. (1979). Energy in UK Agriculture. J. Sci. Food Agric. 30, pp449-457.

Lewis, M.R. (1979). Fish Farming in Great Britain - An Economic Survey With Special Reference to Rainbow Trout. University of Reading, Dept. Ag. Econ. Misc. Study No. 67.

Lin, S.Y. (1940). Fish Culture in Ponds in the New Territories of Hong Kong. J. Hong Kong Fish Res. Station. 1, (2).

Macan, T.T., Mortimer, C.H. and Worthington, E.B. (1942). The Production of Fresh Water Fish for Food. F.B.A. Sci. Publ. No.6.

Mantle, G. and Lawson, S. (1980). Research Needed to Back Growth. Fish Farmer, 3, (3).

Mellanby, K. (1975). Can Britain Feed Itself? Merlin Press. London.

Michaels, V. (1981). Pers. Comm. Carp Farmer. Newhay Fisheries, Selby, Yorks.

Mortimer, C.H. and Hickling, C.F. (1954). Fertilizers in Fish Ponds. Fishery Publ. No.5. Colonial Office. HMSO.

Muller, F. (1978). The Aquacultural Rotation. Aquacultura Hungarica (Svarvas). 1, pp73-79.

Newhay. (1981). Revenue and Running Costs in Carp Farming. Newhay Fisheries Training Course. JNC/ALC 22/9/81.

Nix, J. (1982). Farm Management Pocket Book. 13th. Ed.. Wye College, University of London.

Noble, R. (1975). Growing Fish in Sewage. New Scientist. 31/7/75.

North, R. (1794). The History of Esculent Fish and An Essay on the Breeding of Fish and the Construction of Fish Ponds.

Nugent, C.G. (1978). Integration of the Husbandry of Farm Animals and Fish with Particular Reference to Pig Raising in Tropical Areas. In: Fish Farming and Wastes. Conf. Proc. 4-5 Jan. 1978. (Pastakia, C.M.R. (Ed.)). Inst. Fish Mang./Soc. Chem. Ind.

Opuszynski, K. (1968). Carp Polyculture with Plant-Feeding Fish: Grass Carp and Silver Carp. Bull. Acad. Polonaise Res. Sci. 16, (11).

Opuszynski, K. (1971). Present State and the Perspectives in the Culture of Phytophagous Fish in Europe. Proc. Symp. New ways of Fresh Water Fishery Intensification. Vodnany, Poland.

Parker, J. (1981). Notes of Meeting on Potential Carp Marketing Coop. 30/12/81. Central Council for Agricultural and Horticultural Cooperation.

Pimentel, D. and Pimentel, M. (1979). Food Energy and Society. Edward Arnold.

Pillay, T.V.R. and Dill, W.A. (1979). (Eds.) Advances in Aquaculture. Proc. Conf. Kyoto, Japan. 1976. FAO/Fishing News Books Ltd.

Pillay, T.V.R. (1976). The State of Aquaculture 1976. In: Pillay et.al. (Eds.). (1979).

Pratt, P. (1981). Pers. Comm.. Carp Farmer. Water Lane Fish Farm, Burton Bradstock, Dorset.

Reay, P.J. (1979). Aquaculture. Studies in Biology No.106. Edward Arnold.

Regier, H.A. (1973). Ecological Factors Affecting the Amounts of Protein Harvested from Aquatic Ecosystems. In: Jones, J.G.W.(Ed.). (1973).

Roy, R. (1976). Wastage in the UK Food System. Earth Resources Research Ltd..

Ryder, K. (1981). Pers. Comm. Fish Farmer, Humberside Fisheries.

Schaperclaus, W. (1933). Text Book of Fish Culture. Abstract in Mortimer et.al. (1954).

Smith, E.V. and Swingle, H.S. (1941). Organic Materials as Fertilizers for Fish Ponds. Trans. Am. Fish Soc. 72.

Spartaru, P. (1977). Gut Contents of Silver Carp - and Some Trophic Relations to Other Fish Species in a Polyculture System. *Aquaculture*, 11, pp137-146.

Spedding, C.R.W. (1973). The Meaning of Biological Efficiency. In: Jones, J.G.W. (Ed.) (1973).

Suzuki, R. (1976). The Culture of Common Carp in Japan. In: Pillay et.al. (Eds.). (1979).

Szumiec, J. (1976). Some Experiments on the Intensive Farming of Carp in Poland. In: Pillay et.al. (Eds.). (1979).

Taverner, J. (1600). Certain Experiments Concerning Fish and Fruite: Practised by John Taverner and by Him Published for the benefit of Others. William Ponsonby, London.

Walsingham, Lord. (1980). Pers. Comm. Broadflash Farm Produce Ltd., Thetford, Norfolk.

Wohlfarth, G. (1978). Utilization of Manure in Fish Farming. In: Conf. Proc. Fish Farming and Wastes. (Pastakia, C.M.R. (Ed.)). 4-5 Jan 1978. Inst. Fish Mang. / Soc. Chem. Ind.

Wohlfarth, G. and Schroeder, G.L. (1979). Use of Manure in Fish Farming - A Review. *Ag. Wastes*, 1,(2).

Wolny, P. (1966). Fertilization of Warm Water Fish Ponds in Europe. FAO Symp. Warm Water Fish Culture. May 1966.

Worthington, E.B. (1940). Fresh Water Fisheries in Wartime. In: Mortimer and Hickling. (1954).

Woynarovich, E. (1976). The Feasability of Combining Animal Husbandry with Fish Farming, with Special Reference to Duck and Pig Production. In: Pillay et.al. (Eds.) (1979).

Wright's Construction. (1981). Pers. Comm. Selby Yorks.

Wunder, W. (1949). Progressive Pond Culture of Carp. Erwin Nagele, Stuttgart. Abstract in Mortimer and Hickling (1954).

Yashouv, A. (1971). Interaction Between the Common Carp and the Silver Carp in Fish Ponds. *Bamidgeh*, 23,(3).